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(71) Applicant *(for all designated States except US)*: **ETHERTRONICS, INC.** [US/US]; 9605 Scranton Road, Suite 850, San Diego, CA 92121 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **SHAMBLIN, Jeff** [US/US]; 718 Avenida Leon, San Marcos, CA 92069 (US). **DESCLOS, Laurent** [FR/US]; 7699 Palmilla Drive, Apt. 3208, San Diego, CA 92122 (US). **POILASNE, Gregory** [FR/US]; 3923 Ingraham Street, Apt. V302, San Diego, CA 92109 (US). **ROWSON, Sebastion** [GB/US]; 2609 Pico Place, Apt. 217, San Diego, CA 92109 (US). **PATHAK, Vaneet** [IN/US]; 7693 Palmilla Drive, San Diego, CA 92122 (US).

(74) Agent: **ALBERT, G., Peter, Jr.**; Foley & Lardner, P.O. Box 80278, San Diego, CA 92138-0278 (US).

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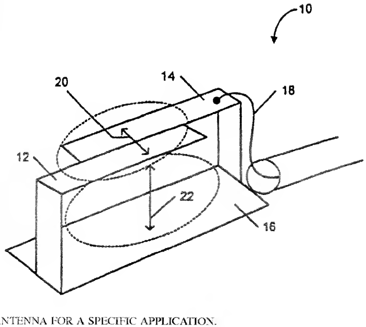
(54) Title: LOW-PROFILE, MULTI-FREQUENCY, MULTI-BAND, CAPACITIVELY LOADED MAGNETIC DIPOLE ANTENNA



(57) Abstract: A DESIGN AND PHYSICAL CONFIGURATION FOR MULTI-FREQUENCY, LOW-PROFILE, CAPACITIVELY LOADED MAGNETIC DIPOLE (CLMD) ANTENNA (10) TO BE USED IN WIRELESS COMMUNICATIONS. ONE COMPONENT OF THE CLMD ANTENNA HAVING ONE TO THREE METAL PLATES (12, 14, 16), AND ONE COMPONENT HAVING ONE TO N ELEMTNES. THE RANGE OF FREQUENCIES COVERED TO BE DETERMINED BY THE SHAPE, SIZE, AND NUMBER OF ELEMENTS IN THE PHYSICAL CONFIGURATION OF THE COMPONENTS. THE ANTENNA CONFIGURATION CAN ALSO BE ADAPTED TO EXPAND FREQUENCY BANDS COVERED BY THE ANTENNA OR TO FIT WITHIN SPACE RESTRICTIONS DICTATED BY SPECIFIC ANTENNA APPLICATIONS. THE ANTENNA (317) CAN ALSO INCLUDE INTEGRATED FILTERS (320) TO FURTHER TUNE THE ANTENNA FOR A SPECIFIC APPLICATION.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

LOW-PROFILE, MULTI-FREQUENCY, MULTI-BAND, CAPACITIVELY LOADED MAGNETIC DIPOLE ANTENNA

BACKGROUND INFORMATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application relates to co-pending application Serial No. 09/892,928, filed on June 26, 2001, entitled "Multi Frequency Magnetic Dipole Antenna Structure and Methods Reusing the Volume of an Antenna" by L. Desclos et al., owned by the assignee of this application and incorporated herein by reference.

This application relates to co-pending application Serial No. 10/076922, entitled "Multi Frequency Magnetic Dipole Antenna Structures with a New E-Field Distribution for Very Low-Profile Antenna Applications" by G. Poilasne et al., owned by the assignee of this application and incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to the field of wireless communications, and particularly to multi-band antennas used in wireless communications.

BACKGROUND

Certain wireless communication applications such as the Global System for Mobile Communications (GSM) and Personal Communications Service (PCS) require that multiple bands be accessible, depending upon the local frequency coverage available from a service provider. Because applications such as GSM and PCS are used in the context of wireless communications devices that have relatively small form-factors, a low profile is also required.

A magnetic dipole antenna (MDA) is a loop antenna that radiates electromagnetic waves in response to current circulating through the loop. The antenna element of an MDA is designed so that it resonates at the frequency required by the ultimate application for which the antenna is intended. The antenna's resonant frequency is dependent on the capacitive and inductive properties of the antenna elements, which in turn are controlled by various dimensions of the antenna elements.

For some applications, it is desirable to expand the frequency range of an antenna to cover a wider band of frequencies. However, size constraints often make it difficult to design an antenna with a frequency band wide enough to meet these applications needs.

In addition, in order to utilize a specific band for a specific application (i.e., in the context of a multi-band-capable antenna), an adjunct piece of hardware like a duplexer or filter can be

used. The subject of the present invention, however, obviates the need for an adjunct duplexer or filter through an integrated filter. These filters can be either in-line or attached directly to the antenna element.

The present invention addresses the requirements of certain wireless communications applications by providing configurations for low profile, multi-frequency, multi-band, capacitively loaded magnetic dipole (CLMDs) antennas.

SUMMARY OF THE INVENTION

The present invention discloses a myriad physical arrangements of multiple antenna elements configured to cover one to *n* number of frequencies or bands of frequencies.

In the present invention, the antenna elements include both inductive and capacitive parts. Each element can provide a single frequency or band of frequency. The physical design of each element can vary, but the design allows for multiple frequencies by using a plurality of antenna elements to provide a multi-frequency antenna. Furthermore, the arrangement of a plurality of antenna elements allows the frequency coverage of the antenna to be enlarged. The antenna elements can be cut, folded, and/or arranged to meet both the frequency and space requirements of a specific application. In one embodiment, a single element has two top plates and a bottom plate. In another embodiment a single element has one u-shaped top plate and one bottom plate. In another embodiment, each antenna element comprises three arms arranged to produce multiple frequency bands. In still another embodiment, each antenna element comprises one u-shaped top plate and one bottom plate.

Each element produces a specific frequency or band of frequencies based on its relative size and shape. Different physical configurations can be considered to adapt the antenna and its elements to the physical environment specific to a particular application. Once the antenna element have been assembled into the desired form for the purposes of matching a frequency or frequency band, they can then be arranged to target multiple bands. In one embodiment, the antenna elements can be place done next to the other. In another embodiment, the antenna elements can be stacked, one on top of another. In yet another embodiment, the elements can be inserted one inside the other.

Multiple elements of relatively the same size can be arranged in various fashions such that the frequency bands produced by each element combine to enlarge each frequency band produced by each element. Alternatively, the multiple elements can be of varying sizes to increase the number of frequency bands produced by the antenna.

The ground and feed points of the antenna can be arranged in various fashions to meet the needs of a specific antenna application. In addition, as mentioned above, filters can be added

to or incorporated into the antenna elements in a variety of ways for frequency matching or to reject unused frequency bands. For example, in one embodiment, the filter is formed by attaching a matching element. In another embodiment, the filter is a formed piece of conductive material that is attached to the underside of one arm of the antenna element. In yet another embodiment, the filter can be formed by removing material from the antenna element. All of the various filter embodiments can further be combined in a variety of physical configurations to meet the requirements of a given application.

A multi-frequency, multiband, capacitively loaded magnetic dipole (CLMD) antenna can be configured by arranging the multiple elements and/or filter embodiments to both meet the frequency and space requirements of the specific application. Further features and advantages of this invention as well as the structure and operation of various embodiments are described in detail below with reference to the accompanying drawings.

This summary does not purport to define the invention. The invention is defined by the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated by reference to the following detailed description, when taken in connection with the accompanying drawings, wherein:

Figure 1A is perspective view of an antenna which can be used as a component in accordance with the present invention;

Figure 1B is a side view of the antenna component of Figure 1A;

Figure 1C is a top view of the antenna component of Figure 1A;

Figure 2A is a top view one embodiment of an antenna in accordance with the present invention;

Figure 2B is a top view of one alternative embodiment of the antenna of Figure 2A;

Figure 3A is a top view of another embodiment of an antenna in accordance with the present invention;

Figure 3B is a frequency graph corresponding to the coverage of the antenna shown in Figure 3A;

Figure 4A is a top view of another embodiment of an antenna in accordance with the present invention;

Figure 4B is a top view of an alternative embodiment of the antenna of Figure 4A;

Figure 4C is a top view of an alternative embodiment of the antenna of Figure 4A;

Figure 4D is a top view of an alternative embodiment of the antenna of Figure 4A;

Figure 5A is a top-view an alternative embodiment of an antenna in accordance with the present invention;
Figure 5B is a side view of the antenna of Figure 5A;
Figure 5C is an alternative embodiment of the antenna of Figure 5A;
Figure 5D is a side view of the antenna of Figure 5C;
Figure 6A is a perspective view of an alternative embodiment of a CLMD antenna component according to the present invention;
Figure 6B is a side view of the CLMD antenna component of Figure 6A;
Figure 6C is a top view of the CLMD antenna component of Figure 6a:
Figure 7A is a top view of an alternative embodiment of a CLMD antenna according to the present invention;
Figure 7B is a top view of an alternative embodiment of the CLMD antenna of Figure 7B;
Figure 8A is a top view of an alternative embodiment of a CLMD antenna according to the present invention;
Figures 8B-D are top views of alternative embodiments of the antenna of Figure 8A;
Figure 9A is a top view of an alternative embodiment of a CLMD antenna component according to the present invention:
Figure 9B is a side view of the antenna component of Figure 9A;
Figure 9C is a side view of an alternative embodiment of the antenna component of Figure 9A;
Figure 10A is a top view of an alternative embodiment of a CLMD antenna component according to the present invention;
Figures 10B is a side view of the antenna component of Figure 10A;
Figures 10C and 10D are side views of alternative embodiments of the antenna component of Figure 10A;
Figure 11A is a top view of an alternative embodiment of a CLMD antenna component according to the present invention;
Figures 11B and 11C are top views of alternative embodiments of the antenna component of Figure 11A;
Figure 12A is a top view of an alternative embodiment of a CLMD antenna component according to the present invention;
Figures 12B and 12C are top views of alternative embodiments of the antenna component of Figure 12A;

Figure 13 is a top view of various antenna components and configures according to the present invention;

Figures 14A and 14 B are top views of alternative embodiment of CLMD antennas according to the present invention;

Figure 15A is a diagram illustrating the top view of an antenna element that includes a filter element in accordance with the invention;

Figure 15B is a diagram illustrating the antenna element of figure 15A with two filter elements in accordance with the invention;

Figure 15C is a diagram illustrating the antenna element of figure 15A with three filter elements in accordance with the invention;

Figure 15D is a diagram illustrating a close up view of the filter element of figure 15A;

Figure 15E is a diagram illustrating an alternative embodiment of the filter element of figure 15D;

Figure 15F is a diagram illustrating another alternative embodiment of the filter element of figure 15D;

Figure 15G is a diagram illustrating still another alternative embodiment of the filter element of figure 15D;

Figure 16 is a plot of the return loss of an exemplary dual-band antenna;

Figure 17 is a plot of the frequency response of the dual-band antenna of figure 16;

Figure 18 is a diagram illustrating the effect of a high pass filter on the frequency response of the dual-band antenna of figure 16;

Figure 19 is a diagram illustrating the effect of a low pass filter on the frequency response of the dual-band antenna of figure 16;

Figure 20 is a plot of the return loss for a tri-band antenna that incorporates filtering in accordance with the invention;

Figure 21A is a diagram illustrating an antenna element comprising an alternative embodiment of a filter element coupled with the antenna element in accordance with the invention;

Figure 21B is a diagram illustrating the antenna element of figure 8A coupled with another alternative embodiment of a filter element in accordance with the invention;

Figure 21C is a diagram illustrating the antenna element of figure 8A coupled with still another alternative embodiment of a filter element in accordance with the invention;

Figure 22A is a diagram illustrating the filter element of figure 21A coupled with two of the filter elements illustrated in figure 21A;

Figure 22B is a diagram also illustrating the filter element of figure 21A coupled with two of the filter elements illustrated in figure 21A arranged in a different location relative to the filter elements of figure 22A;
Figure 22C is a diagram illustrating the filter element of figure 21A coupled with two of the filter elements illustrated in figure 21B;
Figure 22D is a diagram also illustrating the filter element of figure 21A coupled with two of the filter elements illustrated in figure 21B arranged in a different location relative to the filter elements of figure 22C;
Figure 23A is a diagram illustrating an antenna element comprising the filter element of figure 15G and coupled with the filter element of figure 21A;
Figure 23B is a diagram illustrating an antenna element comprising the filter element of figure 15G and coupled with the filter element of figure 21B;
Figure 23C is a diagram illustrating an antenna element comprising the filter element of figure 15G and coupled with the filter element of figure 21C;
Figure 23D is a diagram illustrating an antenna element comprising the filter element of figure 15G and coupled with the filter elements of figures 21B and 21C;
Figure 241A is a diagram illustrating an exemplary single element, multi-band, capacitively loaded antenna;
Figure 24B is a diagram illustrating another exemplary single element, multi-band, capacitively loaded antenna;
Figure 24C is a diagram illustrating still another exemplary single element, multi-band, capacitively loaded antenna.
Figure 25a is a top view of one embodiment of an antenna element according to the present invention;
Figure 25b is a graphical representation of the frequencies produced by the antenna element of Figure 25a;
Figure 26a is a top view of an alternative embodiment of the antenna element of Figure 25a including an inductive bridge between two arms of the element;
Figure 26b is a top view of an alternative embodiment of the antenna element of Figure 25a having slots inserted into one arm of the element;
Figure 26c is a top view of another alternative embodiment of the antenna elements of Figure 25a including an inductive bridge between two arms of the element;
Figure 26d is a top view of another alternative embodiment of the antenna elements of Figure 25a including multiple inductive bridges between two arms of the element;

Figure 26e is a graphical representation of one frequency band produced by the antenna element of Figure 26d;

Figure 26f is a top view of another alternative embodiment of the antenna elements of Figure 25a showing an alternative feeding structure;

Figure 26g is a side view of the antenna element of Figure 26f;

Figure 27a is a perspective view of an alternative embodiment of the antenna of Figure 25a including an external matching arm;

Figure 27b is a perspective view of an alternative embodiment of the antenna of Figure 27a;

Figure 27c is a top view of an alternative embodiment of the antenna element of Figure 25a;

Figure 27d is a top view of an alternative embodiment of the antenna element of Figure 27c;

Figure 27e is a top view of an alternative embodiment of the antenna element of Figure 27c;

Figure 27f is a top view of an alternative embodiment of the antenna element of Figure 27c;

Figure 28 is a top view of an antenna having multiple antenna elements according to the present invention;

Figure 29 is a top view of an alternative embodiment of the antenna of Figure 28 with a modified feeding structure;

Figure 30 is a top view of an alternative embodiment of the antenna of Figure 29;

Figure 31 is a top view of an alternative embodiment of the antenna of Figure 29;

Figure 32 is a top view of an alternative embodiment of the antenna of Figure 31;

Figure 33 is a top view of an alternative embodiment of the antenna of Figure 31;

Figure 34 is a top view of an alternative embodiment of the antenna of Figure 29;

Figure 35a is a top view of an alternative embodiment of an antenna according to the present invention including matching elements and filters;

Figure 35b is a perspective view of the antenna of Figure 35a;

Figure 36 is a top view of an alternative embodiment of the antenna of Figure 28;

Figure 37a is a top view of an alternative embodiment of the antenna of Figure 36 with a modified feeding structure;

Figure 37b is a graphical representation of the frequencies produced by the antenna of Figure 37a;

Figure 38 is a perspective view of an alternative embodiment of an antenna according to the present invention;

Figure 39 is a side view of the antenna of Figure 38;

Figure 40 is a perspective view of an alternative embodiment of an antenna according to the present invention;

Figure 41 is a perspective view of an alternative embodiment of the antenna of Figure 40 including an additional antenna element;
Figure 42 is a perspective view of an alternative embodiment of the antenna of Figure 41;
Figure 43 is a perspective view of an alternative embodiment of the antenna of Figure 42 including an additional antenna element;
Figure 44 is a top view of an alternative embodiment of the antenna of Figure 29 including an additional antenna element;
Figure 45 is a top view of an alternative embodiment of the antenna of Figure 44 with modified feeding structure;
Figure 46 is a top view of an alternative embodiment of the antenna of Figure 44 with additional antenna elements;
Figure 47 is a top view of an alternative embodiment of the antenna of Figure 36 with additional antenna elements; and
Figure 48 is a top view of an alternative embodiment of the antenna of Figure 47 with antenna elements of varying size.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, for purposes of explanation and not limitation, specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details. In other instances, detailed descriptions of well-known methods and devices are omitted so as to not obscure the description of the present invention with unnecessary detail.

A CLMD antenna produces a specific frequency, band of frequency, or combination therein for a targeted applications like Global System for Mobile Communications (GSM) and Personal Communications Service (PCS). The resonant frequency is a result of the inductance and capacitance. CLMD antennas present various advantages, chief among them is excellent isolation. Different configurations of the CLMD antennas are available which have varying degrees of isolation and different bandwidths.

Figure 1A illustrates one embodiment of a single-element CLMD antenna 10 that can be used in accordance with the present invention. The CLMD antenna 10 comprises two top plates 12 and 14, a bottom plate 16, and an antenna feed line 18. The two top plates 12 and 14 create the capacitive part 20 of antenna 10 and the loop between the two top plates 12 and 14 and the bottom plate 16 creates the inductive part 22 of antenna 10. The electric field is confined

in the capacitive part 16 of antenna 10 and the magnetic field is expelled in the inductive part 22 of antenna 10. Power is supplied to the antenna 10 through the feed line 18. In Figure 1A, the feed line 18 is a coaxial cable with the inner conductor connected to one top plate 14 and the outer conductor connected to the bottom plate 16, which serves as ground.

Figure 1B illustrates a side-view of antenna 10. As can be seen the two top plates 12 and 14 create the capacitive part 20 of the antenna 10 while the loop between the two top plates 12 and 14, and the bottom plate 16 creates the inductive part 22. The far field of such an antenna is actually due to the expelled field, mainly magnetic, in the area closely surrounding the antenna 10.

Figure 1C illustrates a top-view of antenna 10 with a horizontal electric field 24 shown between the two top plates 12 and 14 in accordance with the present invention. The horizontal electric field 24 allows for a lower antenna profile, because electric field 24 is confined in a horizontal orientation as opposed to a vertical orientation. The electric field confinement can be optimized and frequency bandwidth can be tuned, at least in part, by adjusting the distance between the two top plates 12 and 14. For example, increasing the distance between the two top plates 12 and 14, which increases the antenna mode volume, can enlarge the frequency bandwidth. Increasing the antenna mode volume will result in more leaks around the antenna. On the other hand, as confinement increases, the isolation increases, but the bandwidth becomes narrower. Thus, isolation and bandwidth can be optimized by adjusting the distance between the two top plates 12 and 14.

Turning now to Figure 2A, one embodiment of a multi-element, multi-frequency, either mono or dual band CLMD antenna in accordance with the present invention is shown as reference numeral 100. Antenna 100 comprises two separate CLMD antenna components 102 and 104, such as antenna 10 shown in Figure 1A, placed one beside the other. The antenna components 102 and 104 each include two top plates 112 and 114, one bottom plate 116, and a feed line 118 connected to one top plate 114. The antenna components 102 and 104 are configured to operate at different frequencies within a specified frequency range. In this configuration, the frequency characteristics of antenna components 102 and 104 combine to give antenna 100 a frequency range including the combined operating frequencies of both antenna components 102 and 104.

An alternative embodiment of the antenna 100 is shown in Figure 2B. In this embodiment, only one antenna component 102 is connected to the feed line 118. In this configuration, antenna component 104 is excited by a magnetic coupling 120 coming from antenna component 102. As in the previous embodiment, each antenna component 102 and 104 is

configured to operate at a different frequency within a specified frequency range giving the resulting antenna 100 a frequency range that includes the combined operating frequencies of both antenna components 102 and 104. In this configuration, 1 to *n* parasitic components can be coupled to the component connected to the feed line 118.

The antenna components 102 and 104 presented in Figures 2A and 2B can be sized for very different frequency ranges making it possible to obtain the multi-frequency, multi-band CLMD antenna 125 shown in Figure 3A. Reference numerals 122 and 124, of Figure 3B, are the graphical representations of the frequencies covered by two larger components 126 and 128, of Figure 3A, and reference numerals 130 and 132 are the graphical representations of the frequencies covered by two smaller components 134 and 136. Larger components 126 and 128 generally provide coverage for lower frequencies, for example in the 800MHz range , while smaller components 134 and 136 provide coverage for higher frequencies, for example in the 1900MHz range. Thus, the frequency coverage for antenna 125 is shown in Figure 3B is the combined coverage of components 126, 128, 134, and 136.

For purposes of this specification and the claims that follow, it can be said that antenna components 102 and 104 in figures 2A and 2B are vertically aligned with respect to each other. Further, it can be said that antenna components 134 and 136 are horizontally aligned with respect to antenna elements 126 and 128 in figure 3A.

Multiple configurations of feeding the components 126, 128, 134 and 136 are contemplated. For example, one component can be connected to a feed line and the others can be excited by magnetic coupling. Alternatively one component in each band (i.e. 800 MHz, 1900MHz) can be connected to a feed line and the other component in each band is excited by magnetic coupling to its counter part in the frequency band. Another possible arrangement would be to connect each component to a feed line.

Figures 4A, 4B, 4C and 4D illustrate the aforementioned feeding solutions plus different component placement. Components corresponding to similar frequency ranges can be placed side-by-side or inserted between the other components. These different configurations can be applied not only to two components of each frequency range but also at *n* components within *m* frequency ranges.

Figure 4A illustrates one embodiment of a multi-element, multi-band CLMD antenna 138, in accordance with the present invention. In this configuration, there are four antenna components 140, 142, 144, and 146, placed parallel to one-another. Components 140 and 146 are the larger components, each covering different frequencies within a relatively lower frequency range. Components 142 and 144, as the smaller of the four components, each

cover different frequencies within a relatively higher frequency range. In this embodiment, power is supplied to each component 140, 142, 144, and 146 through separate feed lines 118. The invention can include 1 to *n* components and one to *n* feed lines.

Figure 4B illustrates an alternative embodiment of the antenna 138 of Figure 4A. In this configuration, the four separate components 140, 142, 144, and 146 again are placed parallel to one-another. However, in this arrangement, the larger components 140 and 146 and smaller components 142 and 144 are interspersed in the following order: 140; 142; 146; and 144. In this embodiment, power is supplied to each component through a separate feed line 118. Again, there can be 1 to *n* components and one to *n* feed lines.

Figure 4C illustrates another alternative embodiment of the antenna 138 of Figure 4A. In this configuration, the two larger components 140 and 146 are grouped next to each other and the two smaller components 142 and 144 are grouped next to each other, with the larger grouping next to the smaller grouping. In this embodiment, power is supplied to the two larger components 140 and 146 through a single feed line 118 attached to component 140. Power is supplied to parasitic component 156 through magnetic coupling 120. Similarly, the two smaller components 142 and 144 are also feed with a single feed line 118 attached to component 142. Power is supplied to parasitic component 144 through magnetic coupling 120.

Figure 4D illustrates alternative embodiment of the antenna 138 of Figure 4B. In this configuration, the larger components 140 and 146 are again interspersed with the smaller components 142 and 144. However, in this embodiment, power is supplied to only one component, in this example larger component 140, through feed line 118. All other components 142, 144, and 146 are powered through magnetic coupling 120, which can supply 1 to *n* elements.

Up to this point, the different embodiments of CLMD antennas have been presented having parallel components. As shown in Figure 5, alternative embodiments of the invention can include stacking the components. The relative direction of one component with regard to the other is on factor in the strength of magnetic coupling between the components. When the components are arranged parallel to each other, the coupling is generally maximized and when they are orthogonal, the coupling is minimized. The two components can also be inserted one into the other for those different directions. If the larger component is placed on top, the smaller component can fit inside. Alternatively, the smaller component can be placed standing over the larger component as presented respectively in Figures 5A-5B and 5C-5D.

Figures 5A and 5B illustrate one embodiment of a multi-element, multi-band CLMD antenna 148 in which the components 150 and 152 are orthogonal to each other, in accordance with the present invention. Figure 5A is a top view, while figure 5B is a side view. In this embodiment, the components 150 and 152 are arranged one inside the other, with the larger component 150 on the outside and the smaller component 152 on the inside. On the horizontal plane, either component 150 or 152 can be arranged to any angle relative to the other from 0 to 360°.

Figures 5C and 5D illustrate an alternative embodiment of the antenna 148 of Figures 5A and 5B. Again, figure 5C is a top view and figure 5D is a side view. In this embodiment, the components 150 and 152 are arranged one on top of the other. In this case, the smaller component 152 is positioned above the larger component 150. Again, on the horizontal plane, either component can be arranged to any angle relative to the other from 0 to 360°.

The aforementioned embodiments of the CLMD antenna 148 of the present invention have excellent isolation due to the high confinement of the electric field. Unfortunately, their bandwidth is relatively narrow. For some applications, the required bandwidth is too wide to use these CLMD antenna components. In order to increase the bandwidth, it is possible to relax the confinement. This relaxation can be obtained using various alternative relaxed component embodiments described below.

Figure 6A illustrates one embodiment of a relaxed single-element CLMD antenna 154 comprising top section antenna element 155, a ground plate 164 and a feed line 118. In this embodiment, the top section antenna element 155 is cut to include two top plates 158 and 160 and a connection section 162 connecting the two top plates 158 and 160 which creates a distributed capacitance 166 in a horizontal electric field as well as an inductance 168.

One way to relax the confinement antenna 154 is to increase the gap 156 between the two top plates 158 and 160. At some point, the capacitance 166 of the antenna 154 becomes too small to keep a low frequency due to the increased gap 156 size between the two top plates 158 and 160. The capacitance 166 reduction can be compensated for by increasing the inductance 168 of the antenna 154. This can be achieved by connecting the two top plates 158 and 160 with a connection section 162. In operation, the two top plates 158 and 160 and connection section 162 form a magnetic dipole field loop 170 shown in Figure 6B.

Similar to the embodiments described above, multiple configurations of multi-element, multi-frequency relaxed CLMD antennas can be assembled using relaxed single element CLMD antennas similar to the one shown in Figures 6A-C. Figure 7A illustrates one embodiment of such a multi-element, either mono or dual band CLMD antenna 170, in accordance with the

present invention. Antenna 170 comprises two top section antenna elements 172 and 174, similar to top section antenna element 155 shown in Figures 6A-C, mounted on a ground plane 164. Alternatively, a separate ground plane can be attached to each top section antenna element. Each top section antenna element 172 and 174 is powered by a feed line 118. The top section antenna elements 172 and 174 are placed parallel to one another and each is configured for covering a specific frequency range.

Figure 7B illustrates an alternative embodiment of the antenna of Figure 7A in which only top section antenna element 172 is powered by a feed line 118. In this embodiment, top section antenna element 174 is powered through magnetic coupling 176 with top section antenna element 172. Magnetic coupling can be used to supply power to 1 to *n* elements.

Figures 8A, 8B, 8C and 8D illustrate different alternative embodiments of a multi-element, multi-band CLMD antenna 178 in accordance with the present invention. The embodiments shown in Figures 8A and 8B each include four top section antenna elements 180, 182, 184 and 186 positioned on a common ground plate 170. Figures 8C and 8D include four top section antenna elements 180, 182, 184 and 186 each positioned on a separate ground plate 188. It should be noted that each of the configurations illustrated in figures 8C and 8D can include a single ground plane 170 or multiple ground planes 188. In fact, this is true for all of the embodiments disclosed herein. Further, it is possible for some top sections to share a common ground plane , while the other top sections either share a separate ground plane or are associated each with their own. For example, in figure 8A top sections 180 and 182 can share a common ground plane, while top sections 184 and 186 either share a ground plane or have their own ground planes. In general, the ground plane configuration for all of the antenna embodiments disclosed herein will depend on the particular implementation.

In figures 8A - 8D, two top section antenna elements are configured for each frequency range (e.g. elements 180 and 186 are configured for one frequency range and elements 182 and 184 are configured for another frequency range) and the different embodiment illustrated in the figures show exemplary physical and powering configurations. Further, in Figures 8A and 8B each top section antenna element 180, 182, 184 and 186 is powered by a feed line 118. In Figure 8C elements 180 and 186 are powered by a feeding line 118, while elements 182 and 184 are powered by magnetic coupling 187 with elements 180 and 186 respectively. In Figure 8D, only element 180 is powered using a feed line 118, while elements 182, 184 and 186 are powered by magnetic coupling 187 with adjacent elements. Elements corresponding to the same frequency range can be placed side-by-side or inserted between elements corresponding to a different frequency range. These different configurations can be applied

not only to two elements of each frequency range but also at *n* elements within *m* frequency ranges.

A relaxed CLMD antenna 190 can also be arranged vertically similar to the CLMD antenna shown in Figure 5. Again, the relative direction of one antenna element related to the other will control the strength of magnetic coupling between the elements. When the elements are parallel, the coupling is maximum and when they are orthogonal, the coupling is minimum. Multiple elements can also be stacked one on top of the other to produce addition embodiment of the invention. In configurations where the top element is larger 192, other elements 194 can fit inside. In configurations where the top element is smaller 194, it can stand over the other elements 192 as presented respectively in Figures 9A-9B and 9C.

The bandwidth obtained with the relaxed CLMD antenna of the type illustrated in Figure 6 may have to be increased for certain applications. In this case, the bandwidth can then be improved further by adding a bridge 157 over the slot of the top plate antenna element 155 as illustrated by the relaxed CLMD antenna 196 presented in Figure 10A.

Various bridge configurations can be applied to the present invention each creating unique ways to control the interaction between the antenna and its surrounding. Several exemplary embodiments are illustrated in Figures 10A, 10B, 10C and 10D. The bridge 157 can be electrically connected on both top plates 158 and 160 as shown in Figure 10B; it can be connected on one top plate 158 and capacitively loaded 198 on the other top plate 160, as shown in Figure 10C; or it can be capacitively loaded 198 on both top plates 158 and 160 as shown in Figure 10D.

Volume and surface area are critical issues for handheld devices. Therefore it can be advantageous to have a dual band antenna component with a low volume and surface area. A relaxed CLMD antenna component can make this because the part of the top plate that is the farthest from the feeding point has very low sensitivity. Therefore, it is possible to inscribe a second, higher frequency in this part of the first element.

Figure 11A illustrates a top-view of one embodiment of a single-element, dual-band CLMD antenna component 2000 where one antenna element 202 is inserted into another antenna element 204, in accordance with the present invention. In this embodiment areas 206 and 208 comprise the capacitive parts respectively for each band while areas 210 and 212 comprise the complementary inductive parts of the antenna 200 to keep a low frequency. Power is supplied to the antenna through a feed line 118.. In this case, the antenna element 202 corresponding to the higher frequency is inserted into the lower frequency antenna element 204 and is oriented toward the same direction.

Figure 11B illustrates an alternative embodiment of a single-element, dual-band CLMD antenna component 200. In this case, the antenna element 202 corresponding to the higher frequency is inserted into the antenna element corresponding to the lower frequency and is oriented in the opposite direction with a mirror symmetry.

Figure 11C illustrates a top-view of an alternative embodiment of a single-element, dual-band CLMD component 200. In this case, the antenna element 204 corresponding to the higher frequency is inserted into the lower frequency antenna element 202 and is oriented in the opposite direction.

Figures 12A, 12B, and 12C illustrate the alternative embodiments of the antenna component 200 of Figures 11A, 11B and 11C respectively, in which bridges 157 are added to improve bandwidth.

Figure 13 summarizes the various antenna embodiments illustrated in the previous figures. The important point is that the different presented solutions can actually be mixed in order to obtain multi-bands. For example, a dual-band relaxed CLMD component can be stacked with a mono-band, relaxed, bridged CLMD component in order to obtain a tri-band antenna.

Figure 14 shows an example of a quad-band, relaxed CLMD antenna component 220. It is comprised of a top plate, tri-band inserted CLMG antenna element 222, stacked with a mono-band regular CLMD antenna element 224 Figure 14B illustrates an alternative embodiment of the antenna component 220 in which the top plate, tri-band inserted CLMG antenna element 222 is bridged 157.

It should also be noted that active or passive components can be placed on the under side of the ground plane of any of the antennas described herein in order to save circuit board real estate within whatever device the antenna is ultimately installed.

The characteristics and operation of several embodiments of an antenna according to the present invention are fully disclosed above. Specifically, figures 6A-6C and the accompanying description detail the various characteristics and operation of a u-shaped single element, capacitively loaded antenna. Antenna 154 can be used as one element of a multi-element antenna configured to operate in a plurality of frequency bands. Essentially, once the elements comprising antenna 154 have been cut and folded into the desired form for the purpose of matching a frequency or frequency band, it can be combined with other single element antennas and arranged to target multiple bands. For example, a plurality of single element antennas, such as antenna 154, can be placed one next to the other, stacked one on top of another, and/or inserted one inside the other. Figures 7A-7B, 8A-8D, and 9A-9C and the accompanying descriptions detail various configurations and arrangements for

constructing a multi-band antenna comprising a plurality of single element antennas. As illustrated in figure 3B, the frequency coverage for the resulting multi-band antenna is then the combined frequency coverage for each of the single element antennas combined to form the multi-band antenna. Thus, for example, a dual-band antenna configured to cover the 800 MHz band and the 1900 MHz band can be formed by combining a single element antenna with coverage in the 800 MHz range with a single element antenna with coverage in the 1900 MHz range.

In Figure 16 of the present application, however, we see that simply combining single element antennas can result in unsatisfactory performance if some type of filtering is not also included. Figure 16 illustrates a return loss plot of a dual band antenna prior to incorporating filtering. As can be seen, one antenna element comprising the dual-band antenna has a response at frequency band 1 (band 1) as illustrated by return loss trace 331. The other antenna element has a response at frequency band 2 (band 2) as illustrated by return loss trace 332. But there are also smaller responses 333 and 334 on the return loss trace due to energy in one band being coupled to the other band. This unwanted coupled energy is due to poor isolation between the two antenna elements that comprise the dual-band antenna. In other words, when one of the elements is excited and therefore begins to resonate at its operating frequency, energy from the excited element is coupled to the other antenna element. This coupling from one element to the other results in the smaller responses 333 and 334, which degrade the performance of the dual-band antenna. With proper isolation, the responses 333 and 334 are suppressed, because little or no energy is coupled from one antenna element to the other.

Figure 17 illustrates a plot 337 of the frequency response of a dual-band antenna that results when one of the antenna elements that comprise the dual-band antenna is excited with a signal. As can be seen, the response actually comprises two responses 335 and 336, one for each band of coverage. Plot 337 illustrates that the rejection between the two frequency bands is poor. The rejection is dependant upon many factors, including: the specific geometry of the antenna; the separation in frequency between the two excited bands, e.g., band 1 and band 2; and the frequency characteristics of the feed lines feeding the respective antenna elements in terms of their inherent filtering characteristics. The isolation and rejection of the dual-band antenna can, however, be improved with the use of filtering as described herein.

To improve the isolation and filtering of a multi-band antenna, a high or low pass filter can, for example be included in one or more feed lines powering the various elements comprising

the multi-band antenna. Alternatively, the filters can be integrated with the antenna elements.

Figure 15A illustrates a top-view of one embodiment of a single antenna element 317 that comprises one element of a multi-element, multi-frequency, capacitively loaded antenna, in accordance with the systems and methods described herein. As with antenna 154 in figure 6A, antenna element 317 also comprises a top plate 311, a ground plate, and a grounding contact; however, for ease of illustration, the ground plate and grounding contact are omitted from figures 15A-15C

Top plate 311 of antenna element 317 is configured in a "U" shape, as with antenna 154 of Figure 6A, comprising two plates 328 and 329 formed such that they are adjacent to and substantially parallel to each other, although it is possible for the two plates 328 and 329 to be oriented in some other manner. A filter element 320 has been added to plate 328 in order to improve the isolation of antenna element 317 relative to at least one other element comprising the multi-element, multi-frequency, capacitively loaded antenna. In this particular embodiment, filter element 320 comprises a cutout 319 that runs the width of plate 328 and that divides plate 328 into two parts. The first part is a cutout plate 321, and the second part is the part formed form the rest of top plate 311, which can be termed the base plate. It will be understood that so configured, cutout plate 321 becomes a parasitic element of antenna element 317. Cutout plate 321 is powered through electro-magnetic coupling, indicated by line 327, with the base plate.

The position and width of cutout 319 can then be tailored to provide the desired filtering characteristics to filter element 320. Essentially, the desired filtering characteristics are those that will allow proper performance of antenna element 317, while improving the isolation and/or rejection, for example, with respect to other antenna elements. Once the geometry of a filter element 320 is defined, the filter element can be replicated in order to add a plurality of filter elements 320 to antenna element 317. Additional filter elements 320 may be added, for example, to further improve the isolation and/or rejection of antenna element 317.

Accordingly, Figure 15B illustrates a top-view of antenna element 317 that comprises two filter elements 320 that divide plate 328 into two cutout plates 322 and 323, each driven by electro-magnetic coupling 327. Figure 15C illustrates a top-view of antenna element 317 that comprises three filter elements 320 that divide plate 328 into three cutout plates 324, 325, and 326, each driven by electro- magnetic coupling 327. More filter elements 320 can be added as required, and each can be driven by electro magnetic coupling 327. Thus, the electro-magnetic coupling can actually be configured to drive form 1 to n cutout plates as required by a particular invention.

Again, once the geometry for a particular filter element 320 is defined, it can be replicated as required to add a plurality of such elements to an antenna element 317. Further, different geometries can be defined to provide different filtering characteristics. For example, figure 15D illustrates a close up view of the embodiment of a filter element 320 illustrated in figure 15A. Figure 15E, on the other hand, illustrates an alternative embodiment of filter element 320 comprising a different geometry. As with the embodiment of figure 15D, the filter element 320 illustrated in figure 15E also comprise a cutout 319 that forms a cutout plate 321 and a base plate 311. Again, electro-magnetic coupling 327 powers cutout plate 321. This creates an example of more complex filter including an inductance and capacitance.

Figure 15F illustrates another alternative embodiment of a filter element 320. Again, the filter element 320 of figure 15F comprises a cutout 319 that divides plate 328 into a cutout plate 321 and a base plate 311, with cutout plate 321 being powered by electro-magnetic coupling 327. This creates an example of more complex filter including an inductance and capacitance.

Figure 15G illustrates still another embodiment of filter element 320. In this embodiment, filter element 320 comprises a plurality of cutouts 319a-319d. But cutouts 319a-319d do not separate plate 328 into two different plates as with previous embodiments. The filter that results from filter element 320 in figure 15G is a second order filter. Thus, the geometries of cutouts 319a-319d can be configured to result in poles in the filter's transfer function at the desired frequencies.

As mentioned, the filters can be high or low pass filters depending on the embodiments and what frequencies need to be rejected. Thus, for example, returning to the frequency response of 337 of a dual-band filter designed in accordance with the systems and methods described herein, one antenna element can include a high pass filter to filter out the lower frequency band (band 1), while the other antenna element includes a low pass filter to filter out the higher frequency band (band 2). Figure 18 illustrates the pass and reject bands of a high-pass filter and the effect the filter has on the two frequency responses of a dual-band antenna. The shaded region 351 indicates the portion of the response that is suppressed by the filtering. Accordingly, a filter element 320 can be configured such that it provides the transfer function 353 illustrated in figure 18.

As mentioned, the filtering can be in the feed line or included in antenna element 317 as described in figure 15A-15G. In either event, however, filter elements 320 can be added to the antenna element to increase the rejection of the filter. Adding filter elements 320

increases the slope 352 of the transfer function 353, which allows greater rejection of band 1 signals.

Figure 19, on the other hand, illustrates the pass and reject band of a low pass filter, which can be incorporated into the feed line or in the antenna element 317. Like the high-pass filter, additional filtering sections 320 can be added to increase the isolation between the two frequency responses, by increasing the slope 352 of transfer function 353. The shaded region 351 indicates the part of the frequency response that is suppressed by the filtering.

Figure 20 illustrates the return loss plot of a tri-band antenna comprising three antenna elements 317 and filtering in accordance with the present invention. The filtering can be included in one or more feed lines and/or in the three antenna elements 317 as described above. The three separate return loss plots 371, 372, and 373 show no additional responses, which is an indication of adequate filtering.

Other types of filtering elements can be used in accordance with the systems and methods described herein, besides those illustrated, for example, in figures 15A-15G. Figure 21A illustrates one embodiment of an antenna element 317 that forms a part of a multi-element, multi-frequency, capacitively loaded antenna, in accordance with the present invention. Again, only top plate 311 of antenna element 317 is shown for simplicity. Antenna element 317 also includes a filter element 381 that serves to reject unsupported frequencies. As shown in the blown up view of figure 21A, filter element 381 comprises a bottom plate 384 that is electro-magnetically connected with plate 316 of top plate 311. Filter element 381 also comprises a plate 385 that extends down from plate 316 in a substantially perpendicular orientation to plate 316. Other orientations for plate 85 relative to plate 316 are of course possible.

Preferably, plate 385 is a capacitive plate, i.e., plate 385 preferably forms a capacitance such that filter element 381 is a capacitive filter element with the desired filtering characteristics. In one embodiment, therefore, plate 385 can, like top plate 311, comprise a cutout section 386 so that plate 385 comprises a "u" shape. So formed, plate 385 can generate a capacitive part of filter element 381 in the same manner that top plate 155 forms a capacitive part 166 of antenna 154 as illustrated in figure 6C.

Other, more complex, filter elements can be generated from the relatively simple capacitive filter element 381. For example, an Inductive-Capacitive (LC)-filter 382 is illustrated in figure 21B. Like filter element 381, filter element 82 can comprise a bottom plate 384 and a capacitive plate 385. In addition, filter element 382 can also include a second plate 387. This second plate 387 can be configured to form an inductive part of filter element 382 in much

the same way that ground plate 164 can be configured to form an inductive part 170 of antenna 154 in figure 6B.

Figure 21C illustrates another possible filter element 383 configured, as with filter elements 381 and 382 to reject unsupported frequencies. In filter element 383, bottom plate 384 has been cut so as to form a second order filter with capacitive plate 385.

Once the basic filter elements are designed, they can be added as needed to antenna element 317. For example, two filter elements 381 can be used if required by a particular implementation as indicated in figure 22A. As indicated in figure 22B, the location of the various filter elements can also be selected based on a particular application's requirements. Thus, one filter element 381 can be added to one arm of filter element 317, while another is added to the connecting section between the two arms. Similar configurations can be implemented using filter elements 382 as indicated in figured 21C and 21D.

In general, it should be remembered that once a filter element is defined, whether it is a cutout filter element 320 or one that is coupled with antenna element 317, such as filter elements 381-383, the filter element can be combined with other similar filter elements or with other types of filter elements to provide the required filtering. Thus, in figure 23A for example, a cutout filter element 401 is combined with a filter element 381. In figure 23B cutout filter 401 is combined with a filter element 382. In figure 10C filter element 401 is combined with a filter element 383. In figure 23D, three filter elements 401, 382, and 383 are combined. But only a small number of the possible combinations of filter elements are illustrated by the embodiments of figures 23A-23D. Therefore, the embodiments of figured 23A-23D should not be viewed as limiting the possible combinations of filter elements. Rather, it should be apparent that any number of filter elements, of any type, can be combined as required by a particular implementation.

It should also be remembered, that the individual antenna elements disclosed herein can be combined to form multi-element, multi-band antennas, such as those disclosed in figures 7A-7B, 8A-8D, and 9A-9C. Thus, one or more filter elements can be added to the antenna elements of the various multi-element, multi-band antennas disclosed in figures 7A-7B, 8A-8D, and 9A-9C as required by a particular application and as described above.

Further, several embodiment of a single element, multi-band antennas are disclosed in figures 24B-24C as well as the figures discussed above. In these embodiments, a single top plate is configured to form multiple antenna elements, each with their own frequency range or band of operation. These single elements, multi-band antennas can also be combined with other antenna elements. For example, figures 14A and 14B and the accompanying description

illustrate how antenna elements can be stacked with the antenna elements of figures 24B-24C. It will be apparent, however, that filter elements, such as those described above, can also be added to such single element, multi-band antennas, whether alone or combined with other antenna elements, in accordance with the methods disclosed herein.

Figure 24A is a diagram of one possible embodiment of such a single element, multi-band antenna 400. Antenna 400 comprises a top plate 470 that has been cut so that it comprises cutouts 410 and 412. The cutouts form three arms 414, 416, and 418, which form two antenna elements. Arms 414 and 416 form the capacitive part 402 of the first element, while arms 416 and 418 form the capacitive part 404 of the second element. The inductive parts of the two elements, 406 and 408 respectively, are formed between ground plate 420 and top plate 470 in the same manner as described in relation to antenna 154 of Figure 6A. Antenna 400 also comprises a ground contact (not shown) between top plate 470 and ground plate 420. Filter elements, such as those described above, can then be added as required, and in accordance with the methods described herein, to antenna 400.

Figure 24B illustrates another exemplary single element, multi-band antenna 424. Cutouts 428 and 446 form three arms 436, 438, and 440, which form two antenna elements. Arms 436 and 438 form the capacitive part 428 of the first element, and arms 438 and 440 from the capacitive part 432 of the other. Antenna 424 also comprise a ground plate and ground contact that are not shown in figure 24B for simplicity. But the ground plate, in conjunction with the top plate 472, forms the inductive parts, 434 and 430, of the two antenna elements respectively. Again, filter elements, such as those described above, can be added as required, and in accordance with the methods described herein, to antenna 424.

Figure 24C illustrates another exemplary single element, multi-band antenna 448. Cutouts 458 and 460 form three arms 462, 464, and 466, which form two antenna elements. Arms 462 and 464 form the capacitive part 450 of the first element, and arms 464 and 466 from the capacitive part 454 of the other. Antenna 448 also comprise a ground plate and ground contact that are not shown in figure 24C for simplicity. But the ground plate, in conjunction with the top plate 474, forms the inductive parts, 456 and 452, of the two antenna elements respectively. Again, filter elements, such as those described above, can be added as required, and in accordance with the methods described herein, to antenna 448.

Another embodiment of an antenna element which can be used according to the present invention is generally designed by reference numeral 510 in Figure 25a. The antenna element 510 comprises three antenna arms 512, 514, and 516. The antenna element 510 is fed through the feeding structure comprising feed line 518 and ground line 520. The antenna arms 512,

514, and 516 are configured to produce circulating current flows which cause the antenna element 510 to radiate at a low frequency (f1) and a high frequency (f2).

Arms 512 and 514 form a large u-shaped antenna element which is fed by feed line 518. This structure produces a current flow indicated by line 522 causing the antenna element 510 to radiate at low frequency (f1). Arms 514 and 516 form a small u-shaped antenna element which is fed through electro-magnetic coupling with arm 512, which is represented by dashed line 524. This small structure produces a current flow which causes the antenna element 10 to radiate at high frequency (f2). This antenna element design creates inductive and capacitive elements which create the antenna frequency bands. For example, arms 512 and 516 form a first capacitive part of antenna 510 and arms 514 and 516 form a second capacitive part. Corresponding inductive parts of the antenna 510 are created between the arms 512, 514 and 516 and a ground plate (not shown except in Figure 39).

Antenna element 510 can be modified for different applications. For example, Figures 26a, 26b and 26c, illustrate various ways to modify the inductance of antenna element 510. Figure 26a shows adding an inductive bridge 526 between arms 512 and 516. The inductive bridge 526 can be used to widen the low frequency band (f1) of antenna element 510. The inductive bridge 526 can also be used to widen the high frequency band (f2) of antenna element 10 by adjusting its placement and width. The effect the inductive bridge 526 has on antenna performance can be controlled to suit many different antenna applications. For example, some of the factors which determine the effect the inductive bridge 526 has on antenna 510 are the width of element 512, the width of the inductive bridge 526, the position of the inductive bridge 526 along the length of element 512, and the width of the gap between elements 512 and 516.

Figure 26c shows adding an inductive bridge 530 between arms 514 and 516. This inductive bridge 530 can be used to widen the high frequency band (f2) of antenna element 510. Similar to inductive bridge 526, inductive bridge 530 can be used to widen the low frequency band (f1) of antenna element 510 by adjusting its placement and width.

Figure 26d show adding multiple inductive bridges 531 between arms 512 and 516. The additional inductive bridges 531 can be used to further widen the low (or high) frequency band of antenna element 510. For example, the embodiment shown in Figure 26d can be configured to produce an expanded low frequency band (f1) like the one shown in Figure 26e. Figure 26b shows inserting slots 528 into arm 512. Slots 528 allow the length of element 512 to be shortened without effecting antenna performance. Figure 26c shows placing an inductive bridge 530 between arms 514 and 516 to widen the bandwidth at the high frequency

(f2), similar to the way inductive bridge 526 operates. Various other modifications can be made to antenna element 510 and various other antenna element configurations can be used for the purposes of the present invention.

Figures 26f-26g show an alternative feeding structure arrangement in which the feed line 518 cut away from arm 512. As shown, the feed line 518 formed from a piece of arm 512 which is cut away and folded down. The ground line 520 is attached to the end of arm 512.

As shown in Figures 27a and 27b, a matching element 521 can be added to the antenna element 510 enabling additional control over the antenna element environment through frequency matching. Matching element 521 capacitively couples with arm 512 of the antenna element 510. In Figure 27a, matching element 521 is connected to arm 512. In Figure 27b, matching element 521 is connected to feed line 518. Whether the matching element 521 is attached to arm 512 of feed line 518 can be dictated by size considerations of the antenna application. The matching element 521 can be configured to widen the frequency bands produced by antenna element 510. Some of the factors which dictate the effect the matching element 521 has on the antenna element 510 include the length of the matching element 521 and the gap between matching element 521 and the antenna element arm 512. For example, the longer the length of the matching element 521, the more it affects the low frequency (f1) component. Conversely, the shorter the length the more it affects the high frequency (f2) component. With respect to the gap, generally the smaller the gap between the matching element 521 and arm 512, the more the high frequency (f2) component is affected and the larger the gap, the more the low frequency (f1) component is affected.

Figures 27c-27f show alternative embodiments of matching element 521. Figure 27c shows matching element 521 extending vertically downward from the outside edge of arm 512. Figure 27d shows matching element 521 attached to the outside edge of arm 512 and extending perpendicular under arm 512 to under arm 516 where it extends parallel under arm 516. Figure 27e shows matching element 521 attached to the outside edge of arm 512 and extending perpendicular under arm 512 to under arm 514 where it extends parallel under arm 514. Figure 27f shows matching element 521 attached to the outside edge of arm 512 and extending under arm 512 at one diagonal to under arm 516 where it extends at another diagonal to under arm 514.

The antenna 532 shown in Figure 28 comprises two antenna elements 534 and 536 fed through a signal feeding structure using feed line 538 and ground line 540. In the embodiment shown in Figure 28, antenna elements 534 and 536 are arranged perpendicular to each other and are connected at their open ends. Both feed line 538 and ground line 540 are

attached to element 534 but are configured to power both element 534 and element 536. This 90 degree arrangement between elements 534 and 536 minimizes coupling between the elements and thus maximizes the bandwidth of antenna 532.

As described above, antenna elements 534 and 536 are each configured to radiate a high frequency and a low frequency, thus producing four separate frequency bands (f1, f2, f3, and f4). The structure of the antenna elements 534 and 536 and their arrangement with respect to each other can be designed such that the low frequencies (f1 and f3) of both elements are near enough on the frequency spectrum to partially combine to form a single, enlarged low frequency band. Similarly, the antenna 532 can be designed such that the high frequencies (f2 and f4) of both elements 534 and 536 are also near enough on the frequency spectrum to partially combine to form a single, enlarged high frequency band. Generally, in order for the antenna elements 534 and 536 to produce frequency bands that combine, antenna elements 534 and 536 should be similarly sized. However, even if elements 534 and 536 are not similarly sized, they can be configured to produce overlapping frequency bands by adjusting the arm lengths and gaps between the arms. Alternatively, the antenna 532 can be configured so that the four frequency bands (f1, f2, f3, and f4) do not overlap allowing them to be used as in a communication system with two separate transmit and receive frequencies. Conversely to the situation described about, generally elements 534 and 536 should be different sized elements in order to produce frequency bands that do not overlap. However, even if elements 534 and 536 are similarly sized, they can be designed to produce non-overlapping frequency bands such as by adjusting the arm lengths and gaps between the arms.

Figure 29 illustrates an alternative feeding structure for the antenna of Figure 28. In Figure 29, ground line 540 is connected to element 536 while feed line 538 is connected to element 534. This feeding structure can be used to power both elements 534 and 536. This and other alternative feed structure arrangements can be made to accommodate size constraints imposed by various antenna applications.

Figure 30 illustrates an alternative embodiment of the antenna shown in Figure 29. In Figure 30, elements 534 and 536 are arranged at an angle 542 less than 90 degrees. This allows the overall structure of the antenna 532 to be more compact allowing it to be used for applications in which space of limited. However, because the elements 534 and 536 are no longer perpendicular, coupling occurs between the elements which can reduce the bandwidth of antenna 532. This coupling can be compensated for in a variety of ways such as, among other ways, adjusting the arm lengths of each element 534, 536 and/or adjusting the gaps between the arms.

Figures 31-33 illustrate various embodiments in which elements 534 and 536 are arranged parallel to each other. In these embodiments, feed line 538 is connected to element 534 and ground line 540 is connected to element 536, however the feed line 538 and ground line 540 could be reversed or both be attached to either element 534 or 536. In this configuration, the coupling between the elements 534, 536 is very high since the magnetic fields created by each element are parallel to each other. In the embodiment shown in Figure 31 the elements 534 and 536 are connected. In Figure 32, the elements 534 and 536 are separated by a distance (d) which can be used to match the elements 534 and 536 return loss and efficiency. The coupling created between elements 534 and 536 decreases as the distance (d) between the elements increases. Conversely, the coupling is increased as the distance (d) decreases. Indirectly, the return loss of the elements 534 and 536 is proportional to the magnetic coupling between the elements 534 and 536. In Figure 33, a matching element 544 is added between elements 534 and 536. Matching element 544 can be used for frequency matching for all frequency bands produced by antenna 532. Thus, matching element 544 can be used to increase the bandwidth of antenna 532. Also, as with the previously described embodiments, the length of the antenna element arms and the gaps between the arms can be adjusted to compensate for coupling and to increase the bandwidth of antenna 532.

Figure 34 illustrates an alternative embodiment of Figure 29 in which the angle between elements 534 and 536 is 180 degrees. In this embodiment, the feed line 538 is moved to the side (rather than the end) of element 534 in order to accommodate the connection between elements 534 and 536. In this embodiment, there is only minimal coupling at the ends of the elements 534 and 536 but little or no magnetic coupling that would affect the bandwidth of antenna 532. This arrangement can be used in antenna applications in which the a long, narrow piece of real estate is available for the antenna.

Figures 35a and 35b illustrate one embodiment of the invention that includes various filters and matching elements to customize and optimize operation of the antenna 546 for a particular application. This embodiment shows various filters 548 cut into antenna element 546. Filters of this type, which allow element 546 to produce multiple frequency bands, are described in more detail above. Antenna 546 also includes a second antenna element 552 and a matching element 554 attached to the sides of antenna element 546. An additional parasitic element 556 can also be included inside antenna 546. Parasitic element 556 is feed through magnetic coupling and is configured to general additional frequency bands. As with the other antenna elements described herein, parasitic element 556 can be configured to produce overlapping frequency bands which combine with the frequency bands produced by the other

antenna elements 546, 552 or can be configured to produce non-overlapping frequency bands. Feed line 518 and ground line 520 are shown attached to element 546.

As shown in Figure 36, antenna elements 534 and 536 can also be different sizes. The size of an antenna element 534, 536 largely dictates its resonant frequency band, i.e. the smaller the antenna element the higher the resonant frequency band. Thus, by making element 536 smaller than element 534, the embodiment of antenna 532 shown in Figure 36 is configured to produce four separate frequency bands, which could be configured as the send and receive bands for two distinct systems such as 800 MHz and 1900 MHz. Alternatively, the different sized antenna elements 534 and 536 shown in Figure 36 could be designed to produce overlapping frequency bands by adjusting various attributes of the antenna elements such as, among other things, the length of the antenna elements arms and/or the gaps between the arms. In this embodiment, the feed line 538 and ground line 540 are both connected to element 536.

Alternatively, as shown in Figure 37a, each antenna element 534 and 536 can be configured with its own feed line 538 and ground line 540. Designing antenna 532 with separate feeding structures for element 534 and 536 may be desirable in situation in which the device that incorporates antenna 532 has more than one module. For example, the device may have separate Bluetooth™ and GSM modules. In this case, it may be desirable to separate each antenna element's feeding structure to take advantage of these separate modules. Figure 37b illustrates the frequencies (f1, f2, f3 and f4) which could be produced by the embodiment of antenna 532 shown in Figure 37a. As is shown, antenna element 534 could be configured to produce the lower frequency send and receive bands (f1, f2), in the 800 MHz range and antenna element 536 could be configured to produce the higher frequency send and receive bands (f3, f4) in the 1900 MHz range.

Figures 38 and 39 illustrate an embodiment of antenna 532 in which elements 534 and 536 are stacked in a vertical manner. Size constraints of an antenna application may require that the separate antenna elements 534 and 536 be stacked in this vertical manner. While there is come magnetic coupling between elements 534 and 536 in this arrangement, the coupling can be controlled and minimized by, among other ways, adjusting the gap between the elements 534, 536 and their alignment with respect to each other. In this embodiment, both elements 534 and 536 have their own feed line 538 and ground line 540. However, the antenna 532 could be designed with one feeding structure by making one of the elements 534 or 536 parasitic as described herein with respect to other embodiment of the invention. In Figure 39, the elements 534 and 536 are shown attached to a ground plane 558. Similar to the

embodiment illustrated in Figure 37a, elements 534 and 536 are different sizes and thus can be configured to produce multiple frequency bands across the spectrum. It should be noted that one advantage to the various antenna arrangements discussed herein is that antenna 532 can be designed to fit within the space constraints of various applications.

Figure 40 illustrates still another embodiment of antenna 532. In this embodiment, antenna element 536 is attached to the side of element 534 facing the same direction but at a 90 degree angle with element 534. This arrangement minimizes coupling between elements 534 and 536 similar to the embodiment illustrated in Figures 28 and 29. Element 536 can be attached to any arm of element 534, facing any direction, in order to accommodate size constraints placed on the antenna 532 by particular antenna applications. Similar to the embodiment illustrated in Figure 36, element 536 is smaller than element 534. Feed line 538 and ground line 540 are attached to element 534.

Figure 41 illustrates an alternative embodiment of the antenna of Figure 40. The antenna 560 shown in Figure 41 includes three antenna elements 562, 564 and 566. Antenna elements 564 and 566 are attached to the sides of element 562 at a 90 degree angle with element 562. Elements 562, 564 and 566 are all different sizes. Thus, each antenna element 562, 564, and 566 can be configured to produce two frequency bands at different places on the frequency spectrum. Similar to how the antenna embodiments shown in Figures 36-40 can be configured to operate with two separate communication systems at different frequency bands, the antenna 560 can be configured to operate with three separate communications each at a different frequency band. Figure 41 shows element 566 facing in a direction opposite to elements 562 and 564, however element 566 can be arranged in the same direction as elements 562 and 564 as shown in Figure 42. In embodiments shown in both Figures 41 and 42, the feed line 568 and ground line 570 are attached to element 562.

Figure 43 illustrates an alternative embodiment of the antenna 560 shown in Figure 42. The antenna 560 shown in Figure 43 includes still another antenna element 572 attached to element 562. Element 572 is arranged in a semi-circular way with elements 564 and 566 in the direction of current flow in element 562. Alternatively, element 572, or elements 564 or 566, could also be arranged in the opposite direction or any combination thereof to accommodate the size constraints placed on the antenna 560 by the particular antenna application. In this embodiment, elements 562, 564, 566, and 572 are all different sizes and are configured to produce eight separate frequency bands in four distinct sections on the frequency spectrum (each element producing a high and low frequency in its respective section of the spectrum). However, as described herein with respect to other embodiments of

the invention, the characteristics of the antenna elements 562, 564, 566, and/or 572 can be designed to allow the different-sized antenna elements to produce overlapping frequency bands. Alternatively, one of more of elements 562, 564, 566, or 572 could be configured to be about the same size as another element thus acting to produce frequencies bands in the same section which combine to expand to the high and low frequency bands produced by the respective elements as described above. In this embodiment, the feed line 568 and ground line 570 are both attached to element 562.

Figure 44 illustrates an alternative embodiment of the antenna shown in Figure 29. The antenna 560 shown in Figure 44 includes three antenna elements 562, 564, and 566 connected together. Elements 562 and 564 are arranged perpendicular to each other and element 566 is arranged between elements 562 and 564 at an angle of less than 90 degrees from element 562. Because element 566 is not perpendicular to elements 562 and 564, come magnetic coupling is likely to occur between elements. However, this coupling can be controlled and minimized, as described herein with respect to other embodiments of the invention, by altering various characteristics of the antenna elements or by adding matching elements. In this embodiment, elements 562, 564, and 566 are approximately the same size and thus could be configured to produce frequency bands that combine to expand the frequency bands produced by a single antenna element. In this embodiment, feed line 568 is attached to element 562 and ground line 570 is attached to element 564. Alternatively, as shown in Figure 45, ground line 570 could be attached to element 566. It is contemplated that other feed line/ground line arrangements are possible and within the scope of this invention.

Figure 46 illustrates an alternative embodiment of the antenna 560 shown in Figure 45. This embodiment of antenna 60 includes six antenna elements 562, 564, 566, 572, 574, and 576 attached together. While feed line 568 is shown attached to element 562 and ground line 570 is shown attached to element 566, the feed line 568 and ground line 570 could be attached to other elements. In this embodiment, the antenna elements 562, 564, 566, 572, 574, and 576 are approximately the same size. Thus, as with the embodiment shown in Figures 44 and 45, the antenna elements 562, 564, 566, 572, 574, and 576 can be configured to produce frequency bands that combine to expand the overall frequency bands produced by antenna 560. Alternatively, the elements 562, 564, 566, 572, 574, and 576 could be configured to be different sizes thus producing frequency bands in distinct sectors of the frequency spectrum as previously described for other antenna embodiment discussed herein. In addition, a combination of same-sized and different-sized elements could be designed to produce expanded frequencies (caused by same-sized elements) in distinct sectors of the frequency

spectrum (caused by different-sized elements). Additional elements can also be added in different planes (as previously discussed) or elements 562, 564, 566, 572, 574, and 576 could be arranged in different planes in order to meet the space requirements of a specific application.

Figure 47 illustrates an alternative embodiment of the antenna shown in Figure 36. The antenna 578 shown in Figure 47 includes one large antenna element 580 and three, same-sized, smaller antenna elements 582, 584 and 586. Feed line 588 and ground line 590 are attached to element 580. Large element 580 can be configured to produce a high and low frequency band in one sector of the frequency spectrum, while the three, same-sized, smaller antenna elements 582, 584, and 586 produce an expanded high and low frequency band in a higher sector of the frequency spectrum than that of the large element 580. As described above, the frequency bands produced by elements 582, 584 and 586 combine to produce the expanded high and low frequency bands in the higher sector.

Figure 48 illustrates an alternative embodiment of the antenna 578 shown in Figure 47. In this embodiment, elements 582, 584, and 586 are different-sized, smaller antenna elements. Thus, each of elements 582, 584 and 586 produce a high and low frequency band in a different sector of the frequency spectrum. In this manner, because each element 580, 582, 584, and 586 produces a high and low frequency band in a distinct sector of the frequency spectrum, the embodiment of the antenna 578 shown in Figure 48 can be configured to operate in four different communication systems which operate at different frequencies. As with other embodiment of the invention described herein, coupling between the elements in the antennas shown in Figures 46-48 can be controlled and/or minimized in a variety of ways and various aspects of the antenna element's design and arrangement can be altered to fit the needs of particular antenna applications.

While embodiments and implementations of the invention have been shown and described, it should be apparent that many more embodiments and implementations are within the scope of the invention. Accordingly, the invention is not to be restricted, except in light of the claims and their equivalents.

WE CLAIM:

1. An antenna, comprising:

a first top plate;

a second top plate adjacent the first top plate, the first and second top plates configured to form a capacitive part of the antenna configured to confine an electric field generated by the antenna in a horizontal plane; and

a ground plane electrically connected with the first and second top plates, the ground plane configured to create an inductive part of the antenna with the first and second top plates, the inductive part configured to expel a magnetic field generated by the antenna.

2. The antenna of claim 1, further comprising a feedline coupled with either the first or second top plate, the feedline configured to supply power to the antenna.

3. The antenna of claim 1, wherein the electric field confinement and a frequency bandwidth of the antenna can be controlled by controlling the separation between the first and second top plates.

4. The antenna of claim 1, further comprising active or passive components installed on the under side of the ground plane in order to save circuit board real estate within a device in which the antenna is installed.

5. A multi-frequency range antenna, comprising a plurality of antenna components each configured to operate in a selected frequency range, each antenna component including:

a first top plate;

a second top plate adjacent to the first top plate, the first and second top plates configured to form a capacitive part of the antenna component configured to confine an electric field generated by the antenna component in a horizontal plane; and

a ground plane electrically connected with the first and second top plates, the ground plane configured to create an inductive part of the antenna component with the first and second top plates, the inductive part configured to expel a magnetic field generated by the antenna component.

6. A multi-frequency range antenna of claim 5, wherein the size of each of the plurality of antenna components is configured so that the antenna operates in the selected frequency range.

7. The multi-frequency range antenna of claim 5, wherein the plurality of antenna component are vertically or horizontally aligned with respect to each other.

8. The multi-frequency range antenna of claim 5, further comprising a plurality of feed lines, wherein each of the plurality of feed lines is coupled to one of the plurality of antenna components, and wherein each of the plurality of feed lines is configured to supply power to the antenna component with which it is coupled.

9. The multi-frequency range antenna of claim 8, wherein any antenna components not coupled with one of the plurality of feed lines is excited through magnetic coupling.

10. The multi-frequency range antenna of claim 5, further comprising a feedline coupled to one of the plurality of antenna components, wherein the feedline is configured to supply power to the antenna component with which it is coupled, and wherein the remaining antenna components are excited through magnetic coupling.

11. The multi-frequency range antenna of claim 5, wherein the antenna components are stacked within or on top of each other.

12. The multi-frequency range antenna of claim 5, wherein at least some of the plurality of antenna components share a common ground plane.

13. The multi-frequency range antenna of claim 5, wherein the selected frequency ranges of the plurality of antenna components comprise a single frequency band.

14. The multi-frequency range antenna of claim 5, wherein the selected frequency ranges of the plurality of antenna components comprise a plurality of frequency bands, and wherein the antenna components are grouped by frequency band.

15. The multi-frequency range antenna of claim 14, wherein antenna components of the same frequency band can be aligned vertically or horizontally with respect to each other.

16. The multi-frequency range antenna of claim 14, wherein antenna components of the same frequency band can be aligned vertically or horizontally with respect to antenna components of other frequency bands.

17. The multi-frequency range antenna of claim 14, wherein the antenna components of the same frequency band can be stacked within or on top of each other.

18. The multi-frequency range antenna of claim 14, wherein the antenna components of the same frequency band can be grouped together next to antenna components of other frequency bands or interspersed with antenna components of other frequency bands.

19. The multi-frequency range antenna of claim 5, further comprising active or passive components installed on the under side of the ground plane in order to save circuit board real estate within a device in which the antenna is installed.

20. An antenna, comprising:

a top section comprising a first top plate, a second top plate adjacent to with the first top plate, and a connection section connecting the first and second top plates, the first and second top plates configured to form a capacitive part of the antenna configured to confine an electric field generated by the antenna in a horizontal plane; and

a ground plane electrically connected with the top section, the ground plane configured to create an inductive part of the antenna with the first and second top plates, the inductive part configured to expel a magnetic field generated by the antenna.

21. The antenna of claim 20, further comprising a feedline coupled with the top section, the feedline configured to supply power to the antenna.

22. The antenna of claim 20, wherein the electric field confinement of the antenna can be controlled by controlling the separation between the first and second top plates.

23. The antenna of claim 20, wherein the connection section controls, at least in part, the frequency bandwidth of the antenna.

24. The antenna of claim 20, further comprising a bridge configured to extend across a gap between the first and second top plates, wherein the inductance of the inductive section is controlled at least in part by the bridge.

25. The antenna of claim 24, wherein the bridge is electrically connected with at least one of the first and second top plates.

26. The antenna of claim 24, wherein the bridge is capacitively loaded with respect to at least one of the first and second top plates.

27. The antenna of claim 20, further comprising active or passive components installed on the under side of the ground plane in order to save circuit board real estate within a device in which the antenna is installed.

28. A multi-frequency range antenna, comprising a plurality of antenna components, each antenna component comprising:

a top section comprising a first top plate, a second top plate adjacent to the first top plate, and a connection section connecting the first and second top plates, the first and second top plates configured to form a capacitive part of the antenna component configured to confine an electric field generated by the antenna component in a horizontal plane; and

a ground plane electrically connected with the top section, the ground plane configured to create an inductive part of the antenna component with the first and second top

plates, the inductive part configured to expel a magnetic field generated by the antenna component.

29. The multi-frequency range antenna of claim 28, wherein the plurality of antenna component are vertically or horizontally aligned with respect to each other.

30. The multi-frequency range antenna of claim 28, further comprising a plurality of feed lines, wherein each of the plurality of feed lines is coupled to one of the plurality of antenna components, and wherein each of the plurality of feed lines is configured to supply power to the antenna component with which it is coupled.

31. The multi-frequency range antenna of claim 30, wherein any antenna components not coupled with one of the plurality of feed lines is excited through magnetic coupling.

32. The multi-frequency range antenna of claim 28, further comprising a feedline coupled to one of the plurality of antenna components, wherein the feedline is configured to supply power to the antenna component with which it is coupled, and wherein the remaining antenna components are excited through magnetic coupling.

33. The multi-frequency range antenna of claim 28, wherein the antenna components are stacked within or on top of each other.

34. The multi-frequency range antenna of claim 28, wherein at least some of the plurality of antenna components share a common ground plane.

35. The multi-frequency range antenna of claim 28, wherein the selected frequency ranges of the plurality of antenna components comprise a single frequency band.

36. The multi-frequency range antenna of claim 28, wherein the selected frequency ranges of the plurality of antenna components comprise a plurality of frequency bands, and wherein the antenna components are grouped by frequency band.

37. The multi-frequency range antenna of claim 36, wherein antenna components of the same frequency band can be aligned vertically or horizontally with respect to each other.

38. The multi-frequency range antenna of claim 36, wherein antenna components of the same frequency band can be aligned vertically or horizontally with respect to antenna components of other frequency bands.

39. The multi-frequency range antenna of claim 36, wherein the antenna components of the same frequency band can be stacked within or on top of each other.

40. The multi-frequency range antenna of claim 36, wherein the antenna components of the same frequency band can be grouped together next to antenna components of other frequency bands or interspersed with antenna components of other frequency bands.

41. The multi-frequency range antenna of claim 28, further comprising active or passive components installed on the under side of the ground plane in order to save circuit board real estate within a device in which the antenna is installed.

42. A multi-frequency band antenna, comprising:
a top section, the top section comprising a plurality of antenna components, each of the plurality of antenna components comprising:

a first top plate a second top plate adjacent to the first top plate, and a connection section connecting the first and second top plates, the first and second top plates configured to form a capacitive part of the antenna component configured to confine an electric field generated by the antenna component in a horizontal plane; and

a ground plane electrically connected with the top section, the ground plane configured to create an inductive part of each of the plurality of the antenna components with the first and second top plates of each of the plurality of antenna components, the inductive part configured to expel a magnetic field generated by each of the plurality of antenna components.

43. The multi-frequency band antenna of claim 42, wherein at least some of the antenna components of the plurality of antenna components share at least on of the first and second top plates in common with other antenna components of the plurality of antenna components.

44. The multi-frequency band antenna of claim 42, further comprising a feedline coupled with the top section, the feedline configured to supply power to the multi-frequency band antenna.

45. The multi-frequency band antenna of claim 42, wherein the electric field confinement of each of the plurality of antenna components can be controlled by controlling the separation between the first and second top plates of each of the plurality of antenna components.

46. The multi-frequency band antenna of claim 42, further comprising a bridge configured to extend across a gap between the first and second top plates of one of the plurality of antenna components, wherein the inductance of the inductive section of antenna component is controlled at least in part by the bridge.

47. The multi-frequency band antenna of claim 46, wherein the bridge is electrically connected with the first and second top plates of the antenna component.

48. The multi-frequency band antenna of claim 46, wherein the bridge is capacitively loaded with respect to at least one of the first and second top plates of the antenna component.

49. The multi-frequency band antenna of claim 42, further comprising a mono-band antenna stacked inside the cavity created between the top section and ground plane.

50. The multi-frequency band antenna of claim 42, further comprising active or passive components installed on the under side of the ground plane in order to save circuit board real estate within a device in which the antenna is installed.

51. An antenna element, comprising:
a top plate, the top plate comprising a first arm and a second arm adjacent to the first arm, the first and second arms configured to form a capacitive part of the antenna element;
a filter element; and

a ground plate electrically connected with the first and second arms, the ground plate configured to create an inductive part of the antenna element with the first and second arms.

52. The antenna element of claim 51, wherein the filter element comprises a cutout configured such that the first arm comprises a cutout plate and a base plate.

53. The antenna element of claim 52, wherein the cutout comprises a geometry, the geometry configured such that the cutout, the cutout plate, and the base plate form a capacitive filter element with desired filtering characteristics.

54. The antenna element of claim 52, wherein the cutout plate is powered by electro-magnetic coupling from the base plate.

55. The antenna element of claim 51, wherein the filter element comprises a plurality of cutouts configured to form a second order filter element, the second order filter element comprising desired filtering characteristics.

56. The antenna element of claim 51, wherein the filter element comprises a capacitive plate and a bottom plate electrically coupled with the first arm and the capacitive plate.

57. The antenna element of claim 56, wherein the capacitive plate comprises a geometry, the geometry configured such that the capacitive plate forms a capacitive filter element with desired filtering characteristics.

58. The antenna element of claim 56, wherein the bottom plate comprises a cutout or a plurality of cutouts, the cutout or the plurality of cutouts configured such that the cutout or the plurality of cutouts and the capacitive plate form a second order filter element with desired filtering characteristics.

59. The antenna element of claim 57, wherein the filter element comprises a second plate configured to form a LC-filter element with the first plate, the LC-filter element comprising desired filtering characteristics.

60. The antenna element of claim 51, further comprising a plurality of filter elements, each of the plurality of filter elements configured to reject a certain frequency.

61. The antenna element of claim 51, further comprising a connection section connecting the first and second arms, the connection section comprising a filter element configured to reject a certain frequency.

62. The antenna element of claim 61, wherein the connection section further comprises a plurality of filter elements, each of the plurality of filter elements configured to reject a certain frequency.

63. A multi-band antenna comprising a plurality of antenna elements, each of the plurality of antenna elements comprising:

a top plate, the top plate comprising a first arm and a second arm adjacent to the first arm, the first and second arms configured to form a capacitive part of the antenna element;

a filter element; and

a ground plate electrically connected with the first and second arms, the ground plate configured to create an inductive part of the antenna element with the first and second arms.

64. The multi-band antenna element of claim 63, wherein the filter element of at least one of the plurality of antenna elements comprises a cutout configured such that the first arm comprises a cutout plate and a base plate.

65. The antenna element of claim 64, wherein the cutout comprises a geometry, the geometry configured such that the cutout, the cutout plate, and the base plate form a capacitive filter element with desired filtering characteristics.

66. The antenna element of claim 64, wherein the cutout plate is powered by electro-magnetic coupling from the base plate.

67. The antenna element of claim 63, wherein the filter element of at least one of the plurality of antenna elements comprises a plurality of cutouts configured to form a second

order filter element, the second order filter element comprising desired filtering characteristics.

68. The antenna element of claim 63, wherein the filter element of at least one of the plurality of antenna elements comprises a capacitive plate and a bottom plate electrically coupled with the first arm and the capacitive plate.

69. The antenna element of claim 68, wherein the capacitive plate comprises a geometry, the geometry configured such that the capacitive plate forms a filter element with desired filtering characteristics.

70. The antenna element of claim 68, wherein the bottom plate comprises a cutout or a plurality of cutouts, the cutout or the plurality of cutouts configured such that the cutout or the plurality of cutouts and the capacitive plate form a second order filter element with desired filtering characteristics.

71. The antenna element of claim 69, wherein the filter element comprises a second plate configured to form a LC-filter element with the first capacitive plate, the LC-filter element comprising with desired capacitive characteristics.

72. The antenna element of claim 63, wherein at least one of the plurality of antenna elements further comprises a plurality of filter elements, each of the plurality of filter elements configured to reject a certain frequency.

73. The antenna element of claim 63, wherein at least one of the plurality of antenna elements further comprises a connection section connecting the first and second arms, the connection section comprising a filter element configured to reject a certain frequency.

74. The antenna element of claim 63, wherein the connection section further comprises a plurality of filter elements, each of the plurality of filter elements configured to reject a certain frequency.

75. A single element, multi-band antenna, comprising:

a top plate, the top plate comprising a plurality of arms configured to form a plurality of antenna elements and to from the capacitive part of each of the plurality of antenna elements;

a filter element; and

a ground plate electrically connected with the plurality of arms, the ground plate configured to create an inductive part of each of the plurality of antenna elements with the plurality of arms.

76. The single element, multi-band antenna of claim 75, wherein the filter element comprises a cutout configured such that one of the plurality of arms comprises a cutout plate and a base plate.

77. The single element, multi-band antenna of claim 76, wherein the cutout comprises a geometry, the geometry configured such that the cutout, the cutout plate, and the base plate form a capacitive filter element with desired filtering characteristics.

78. The single element, multi-band antenna of claim 76, wherein the cutout plate is powered by electro-magnetic coupling from the base plate.

79. The single element, multi-band antenna of claim 75, wherein the filter element comprises a plurality of cutouts configured to form a second order filter element, the second order filter element comprising desired filtering characteristics.

80. The single element, multi-band antenna of claim 75, wherein the filter element comprises a capacitive plate and a bottom plate electrically coupled with one of the plurality of arms and the capacitive plate.

81. The single element, multi-band antenna of claim 80, wherein the capacitive plate comprises a geometry, the geometry configured such that the capacitive plate forms a capacitive filter element with desired filtering characteristics.

82. The single element, multi-band antenna of claim 80, wherein the bottom plate comprises a cutout or a plurality of cutouts, the cutout or the plurality of cutouts configured such that the cutout or the plurality of cutouts and the capacitive plate form a second order filter element with desired filtering characteristics.

83. The single element, multi-band antenna of claim 81, wherein the filter element comprises a second plate configured to form a LC-filter element with the first plate, the LC-filter element comprising desired filtering characteristics.

84. The single element, multi-band antenna of claim 75, further comprising a plurality of filter elements, each of the plurality of filter elements configured to reject a certain frequency.

85. The single element, multi-band antenna of claim 75, further comprising connection sections connecting the plurality of arms, wherein at least one of the connection sections comprises a filter element configured to reject a certain frequency.

86. The antenna element of claim 35, wherein the connection section further comprises a plurality of filter elements, each of the plurality of filter elements configured to reject a certain frequency.

87. A multi-frequency band antenna comprising:

a first antenna element including first, second, and third arms, the first and second arms configured to produce a first capacitive part of the antenna and the second and third arms configured to produce a second capacitive part of the antenna to confine an electric field generated by the antenna in a horizontal plane;

a second antenna element including fourth, fifth, and sixth arms, the fourth and fifth arms configured to produce a third capacitive part of the antenna and the fifth and sixth arms configured to produce a fourth capacitive part of the antenna to confine an electric field generated by the antenna in a horizontal plane;

a ground plate arranged adjacent to the first and second antenna elements, the ground plate and first antenna element configured to produce first and second inductive parts of the antenna and the ground plate and second antenna element configured to produce third and fourth inductive parts of the antenna, the inductive parts of the antenna configured to expel a magnetic field generated by the antenna;

the first and second antenna elements each being configured to produce a low frequency band and a high frequency band thus enabling the antenna to communicate on a variety of frequency bands.

88. The antenna of claim 87, wherein the second antenna element is configured to produces an overlapping low frequency band which overlaps and combines with the low frequency band produced by the first antenna element to create an expanded low frequency band.

89. The antenna of claim 87, wherein the second antenna element is configured to produces an overlapping high frequency band which overlaps and combines with the high frequency band produced by the first antenna element to create an expanded high frequency band.

90. The antenna of claim 88 wherein the first and second antenna elements are similarly-sized.

91. The antenna of claim 89 wherein the first and second antenna elements are similarly-sized.

92. The antenna of claim 88 wherein the first and second antenna elements are different sized and the fourth, fifth, and sixth arms are configured to compensate for the difference in sizing between the first and second antenna elements enabling the second antenna element to produce the overlapping low frequency band.

93. The antenna of claim 89 wherein the first and second antenna elements are different sized and the fourth, fifth, and sixth arms are configured to compensate for the difference in sizing between the first and second antenna elements enabling the second antenna element to produce the overlapping high frequency band.

94. The antenna of claim 87 wherein the second antenna element is configured to produces a second low frequency band which does not overlap or combine with the low frequency band produced by the first antenna element enabling the antenna operate in two low frequency bands.

95. The antenna of claim 87 wherein the second antenna element is configured to produces a second high frequency band which does not overlap or combine with the high frequency band produced by the first antenna element enabling the antenna to operate in two high frequency bands.

96. The antenna of claim 94 wherein the first and second antenna elements are different sizes.

97. The antenna of claim 95 wherein the first and second antenna elements are different sizes.

98. The antenna of claim 94 wherein the first and second antenna elements are similarly-sized and the fourth, fifth, and sixth arms are configured to compensate for the similarity in sizing between the first and second antenna elements enabling the second antenna element to produce the non-overlapping second low frequency band.

99. The antenna of claim 95 wherein the first and second antenna elements are similarly-sized and the fourth, fifth, and sixth arms are configured to compensate for the similarity in sizing between the first and second antenna elements enabling the second antenna element to produce the non-overlapping second low frequency band.

100. The antenna of claim 87 wherein the first and second antenna elements are arranged perpendicular to each other to minimize coupling between the elements.

101. The antenna of claim 87 wherein the first and second antenna elements are arranged at an angle of less than 90 degrees from each other.

102. The antenna of claim 87 wherein the first and second antenna elements are arranged at an angle of greater than 90 degrees from each other.

103. The antenna of claim 87 wherein the first and second antenna elements are arranged at an angle of 180 degrees from each other.

104. The antenna of claim 87 wherein the first and second antenna elements are stacked vertically with respect to each other.

105. The antenna of claim 87 further comprising 1 to *n* additional antenna elements, each antenna element having three arms and being configured to produce a low frequency band and a high frequency band.

106. The antenna of claim 87 further comprising a feeding structure including a feeding line and a ground line.

107. The antenna of claim 87 further comprising an inductive bridge between two arms of either the first or second antenna element for widening either the low frequency band or the high frequency band of the element.

108. The antenna of claim 87 further comprising slots in at least one arm of either the first or second antenna elements for enabling a more compact antenna design.

109. The antenna of claim 87 further comprising a matching element for providing frequency matching for the antenna.

110. The antenna of claim 87 further comprising at least one slot filter cut into either the first antenna element or the second antenna element.

111. A multi-frequency band antenna comprising:

two to *n* antenna elements, each antenna element including first, second, and third arms, the first and second arms configured to produce a first capacitive part of the antenna and the second and third arms configured to produce a second capacitive part of the antenna to confine an electric field generated by the antenna in a horizontal plane;

a ground plate arranged adjacent to the two to *n* antenna elements, the ground plate and each one of the two to *n* antenna elements configured to produce inductive parts of the antenna, the inductive parts of the antenna configured to expel a magnetic field generated by the antenna;

each one of the two to *n* antenna elements being configured to produce an overlapping low frequency band and an overlapping high frequency band configured to combine with the overlapping low and high frequency bands, respectively, produced by the other antenna elements to produce an expanded low frequency band and an expanded high frequency band.

112. The antenna of claim 111 wherein the two to *n* antenna elements are similarly sized.

113. The antenna of claim 111 wherein the two to *n* antenna elements are different sizes and the first, second, and third arms of each of the two to *n* antenna elements are configured to compensate for the difference in sizing between the antenna elements thus enabling the antenna elements to produce the overlapping low and high frequency bands.

114. The antenna of claim 111 wherein the two to n antenna elements are arranged perpendicular to each other to minimize coupling between the elements.

115. The antenna of claim 111 wherein the two to n antenna elements are arranged at an angle of less than 90 degrees from each other.

116. The antenna of claim 111 wherein the two to n antenna elements are arranged at an angle of greater than 90 degrees from each other.

117. The antenna of claim 111 wherein the two to n antenna elements are stacked vertically with respect to each other.

118. The antenna of claim 111 further comprising a feeding structure including a feeding line and a ground line.

119. The antenna of claim 111 further comprising an inductive bridge between two arms of any of the two to n antenna elements for widening either the low frequency band or the high frequency band of the element.

120. The antenna of claim 111 further comprising at least one slot in at least one arm of any of the two to n antenna elements for enabling a more compact antenna design.

121. The antenna of claim 111 further comprising a matching element for providing frequency matching for the antenna.

122. The antenna of claim 111 further comprising at least one slot filter cut into any of the two to n antenna elements.

123. The antenna of claim 111 further comprising:

one to m additional antenna elements each additional antenna element including first, second, and third arms, the first and second arms configured to produce a first capacitive part of the antenna and the second and third arms configured to produce a second capacitive part of the antenna to confine an electric field generated by the antenna in a horizontal plane;

each one of the one to m additional antenna elements being configured to produce a distinct low frequency band and a distinct high frequency band enabling the antenna to communicate in a plurality of different frequency bands.

124. The antenna of claim 123 wherein the one to m additional elements are different sizes than the two to n antenna elements.

125. The antenna of claim 123 wherein the one to m additional elements are similarly in size to the two to n antenna elements and wherein the first, second, and third arms of each of the one to m antenna elements are configured to compensate for the similarity in

sizing between the one to m and two to n antenna elements thus enabling the one to m antenna elements to produce the distinct low and high frequency bands.

126. A multi-frequency band antenna comprising:

two to n antenna elements, each antenna element including first, second, and third arms, the first and second arms configured to produce a first capacitive part of the antenna and the second and third arms configured to produce a second capacitive part of the antenna to confine an electric field generated by the antenna in a horizontal plane;

a ground plate arranged adjacent to the two to n antenna elements, the ground plate and each one of the two to n antenna elements configured to produce inductive parts of the antenna, the inductive parts of the antenna configured to expel a magnetic field generated by the antenna;

each one of the two to n antenna elements being configured to produce a distinct low frequency band and a distinct high frequency band enabling the antenna to communicate in a plurality of frequency bands.

127. The antenna of claim 126 wherein the two to n antenna elements are different sizes.

128. The antenna of claim 126 wherein the two to n antenna elements are similar in size and the first, second, and third arms of each of the two to n antenna elements are configured to compensate for the similarity in sizing between the antenna elements thus enabling the antenna elements to produce the distinct low and high frequency bands.

129. The antenna of claim 126 wherein the two to n antenna elements are arranged perpendicular to each other to minimize coupling between the elements.

130. The antenna of claim 126 wherein the two to n antenna elements are arranged at an angle of less than 90 degrees from each other.

131. The antenna of claim 126 wherein the two to n antenna elements are arranged at an angle of greater than 90 degrees from each other.

132. The antenna of claim 126 wherein the two to n antenna elements are stacked vertically with respect to each other.

133. The antenna of claim 126 further comprising a feeding structure including a feeding line and a ground line.

134. The antenna of claim 126 further comprising an inductive bridge between two arms of any of the two to n antenna elements for widening either the low frequency band or the high frequency band of the element.

135. The antenna of claim 126 further comprising at least one slot in at least one arm of any of the two to *n* antenna elements for enabling a more compact antenna design.

136. The antenna of claim 126 further comprising a matching element for providing frequency matching for the antenna.

137. The antenna of claim 126 further comprising at least one slot filter cut into any of the two to *n* antenna elements.

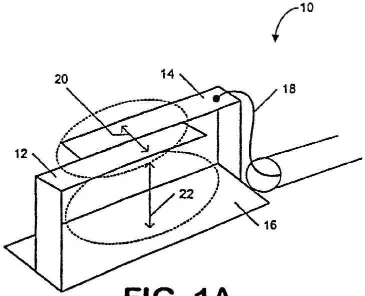


FIG. 1A

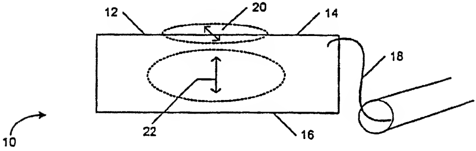


FIG. 1B

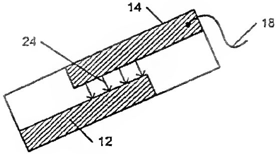


FIG. 1C

SUBSTITUTE SHEET (RULE 26)

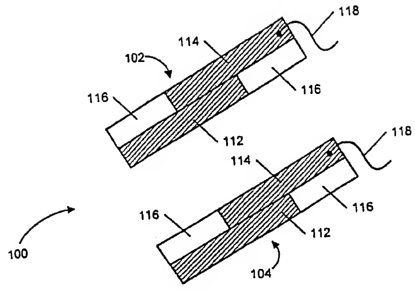

118
114
102
116
116
112
118
114
116
116
112
100
104

FIG. 2A

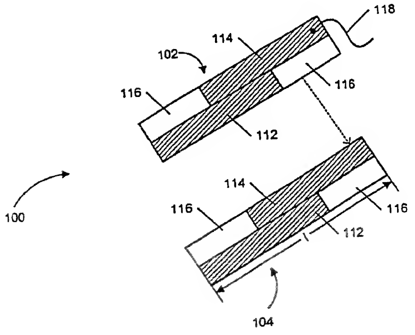

118
114
102
116
116
112
114
116
116
100
112
104

FIG. 2B

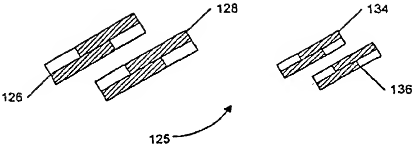


FIG. 3A

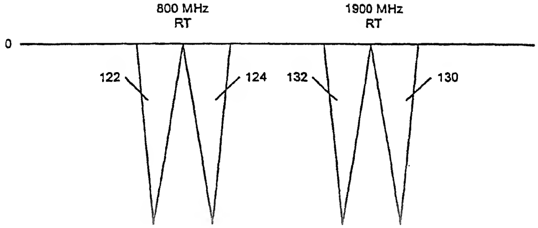


FIG. 3B

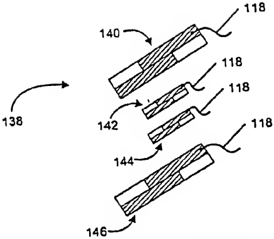


FIG. 4A

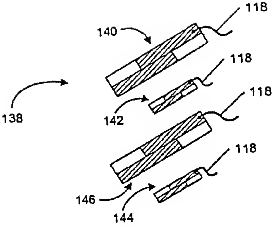


FIG. 4B

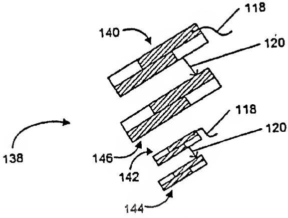


FIG. 4C

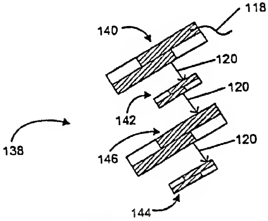


FIG. 4D

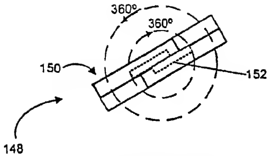


FIG. 5A

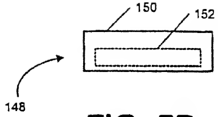


FIG. 5B

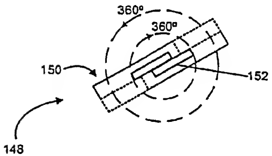


FIG. 5C

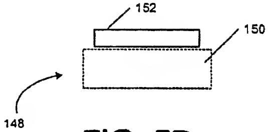
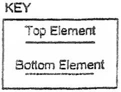


FIG. 5D



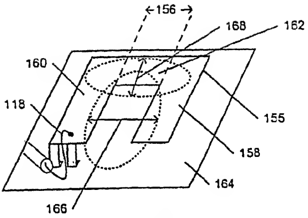


FIG. 6A

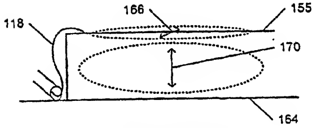


FIG. 6B

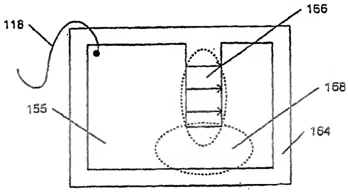


FIG. 6C

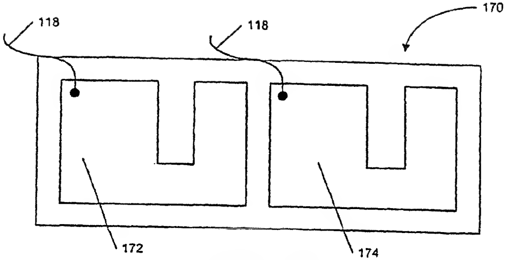


FIG. 7A

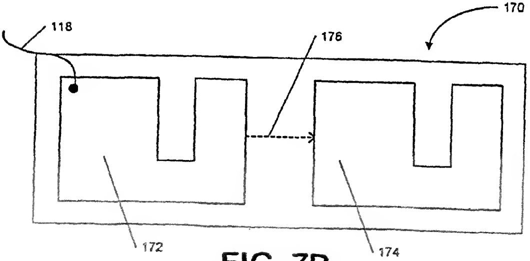


FIG. 7B

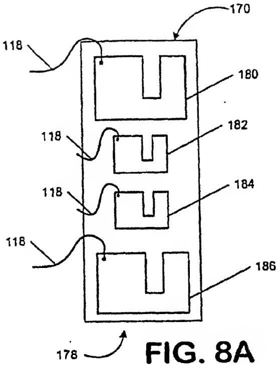


FIG. 8A

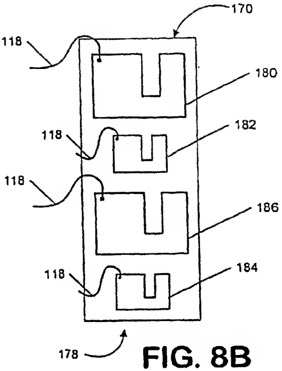


FIG. 8B

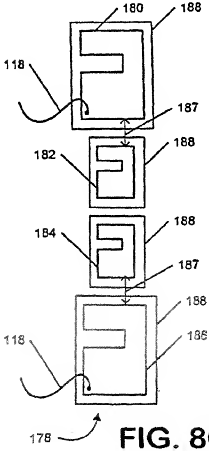


FIG. 8C

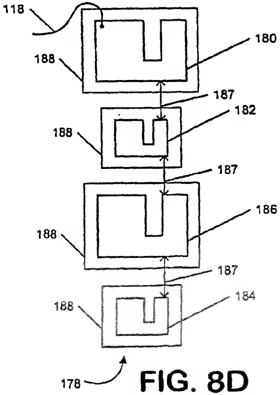


FIG. 8D

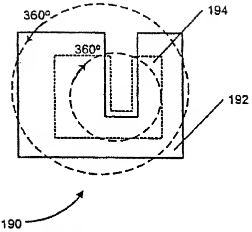


FIG. 9A

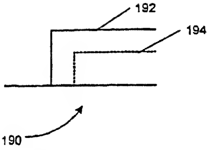


FIG. 9B

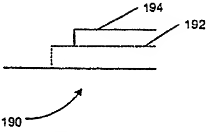


FIG. 9C

KEY

Top Element

Bottom Element

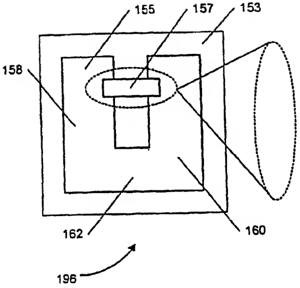


FIG. 10A

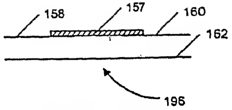


FIG. 10B

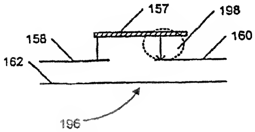


FIG. 10C

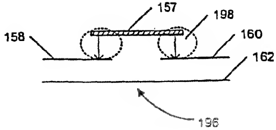


FIG. 10D

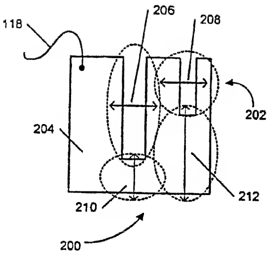


FIG. 11A

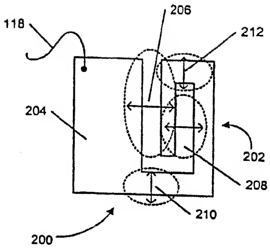


FIG. 11B

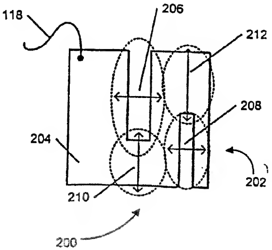


FIG. 11C

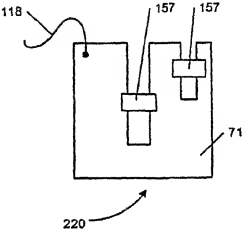


FIG. 12A

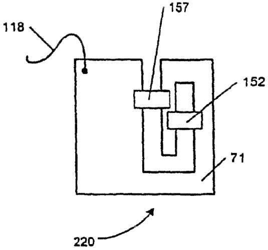


FIG. 12B

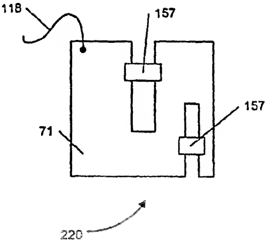


FIG. 12C

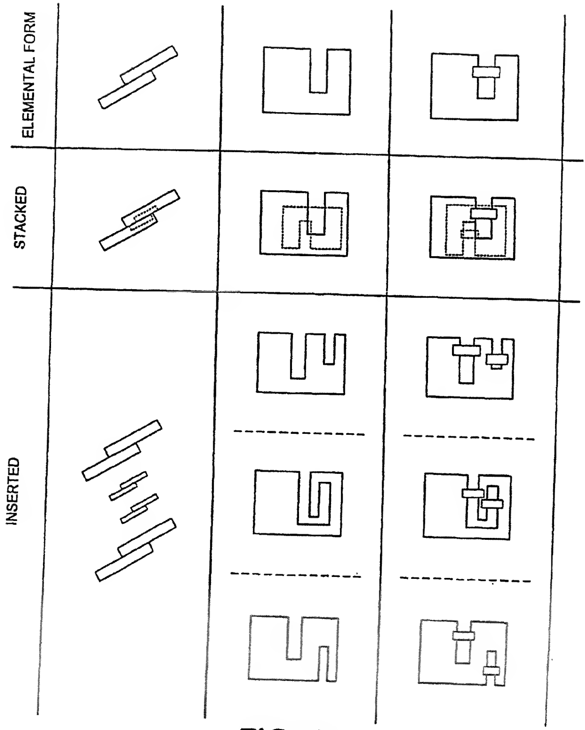


FIG. 13

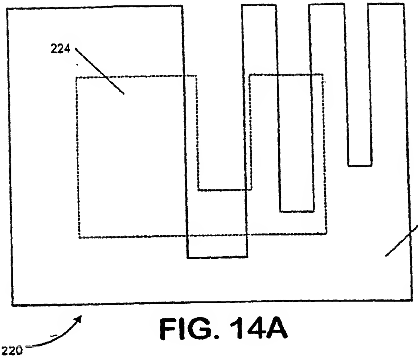


FIG. 14A

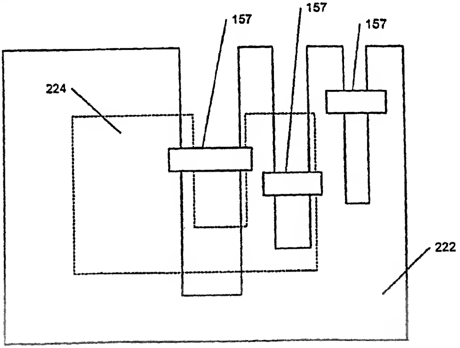
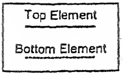


FIG. 14B

KEY



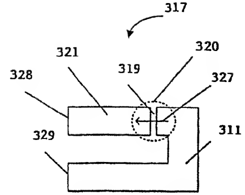


FIG. 15A

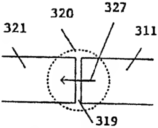


FIG. 15D

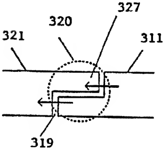


FIG. 15E

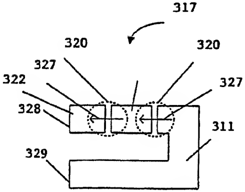


FIG. 15B

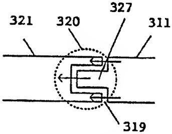


FIG. 15F

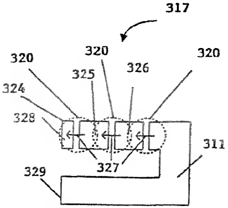


FIG. 15C

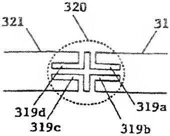


FIG. 15G

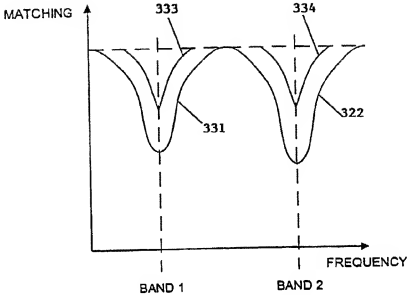

MATCHING
333
334
331
322
FREQUENCY
BAND 1
BAND 2

FIG. 16

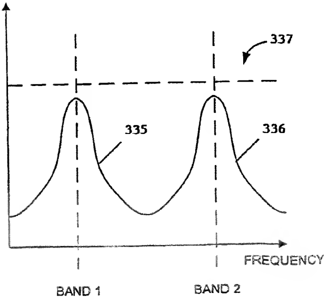

337
335
336
FREQUENCY
BAND 1
BAND 2

FIG. 17

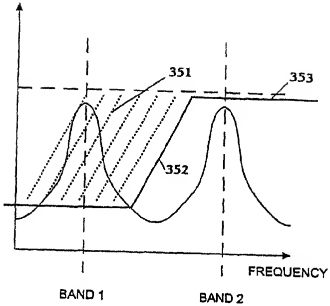

351
353
352
FREQUENCY
BAND 1
BAND 2

FIG. 18

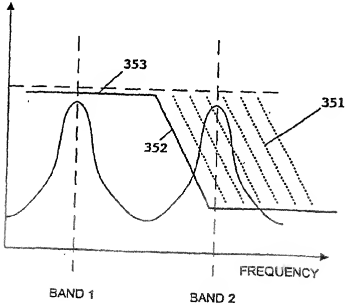

353
351
352
FREQUENCY
BAND 1
BAND 2

FIG. 19

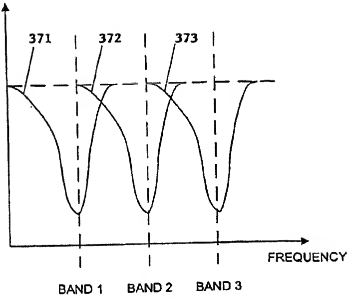


FIG. 20

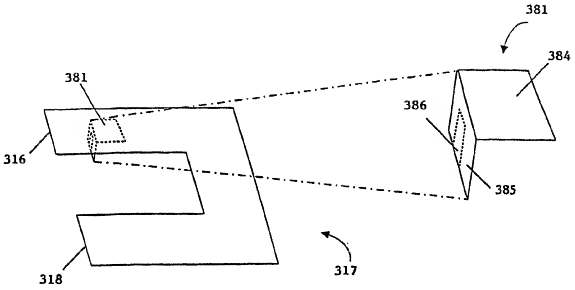


FIG. 21A

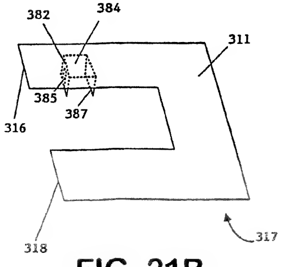


FIG. 21B

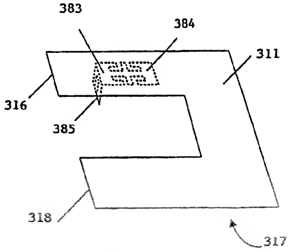


FIG. 21C

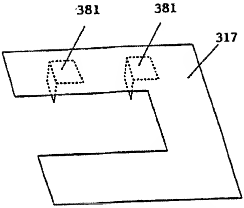


FIG. 22A

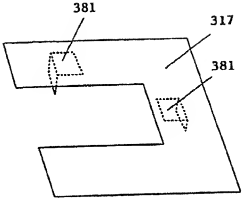


FIG. 22B

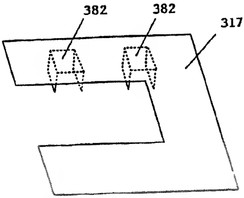


FIG. 22C

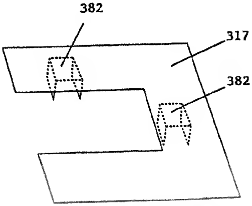


FIG. 22D

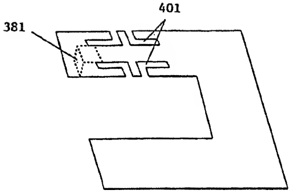


FIG. 23A

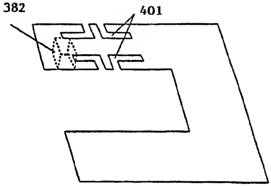


FIG. 23B

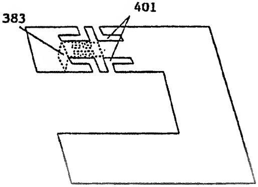


FIG. 23C

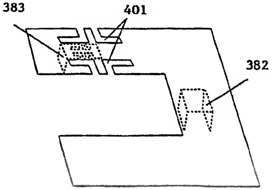


FIG. 23D

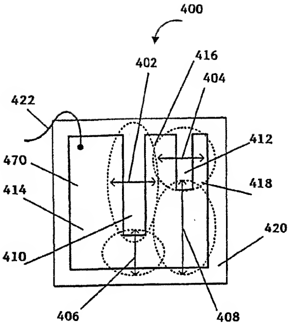


FIG. 24A

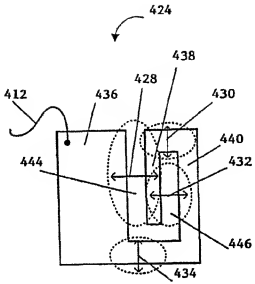


FIG. 24B

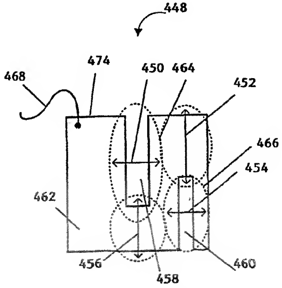


FIG. 24C

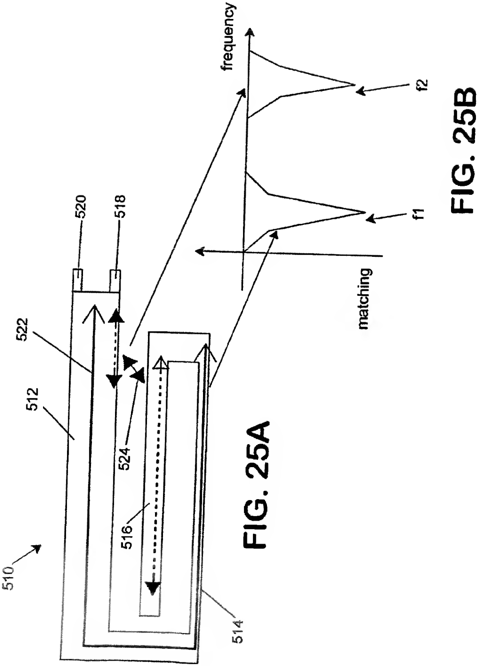


FIG. 25A

FIG. 25B

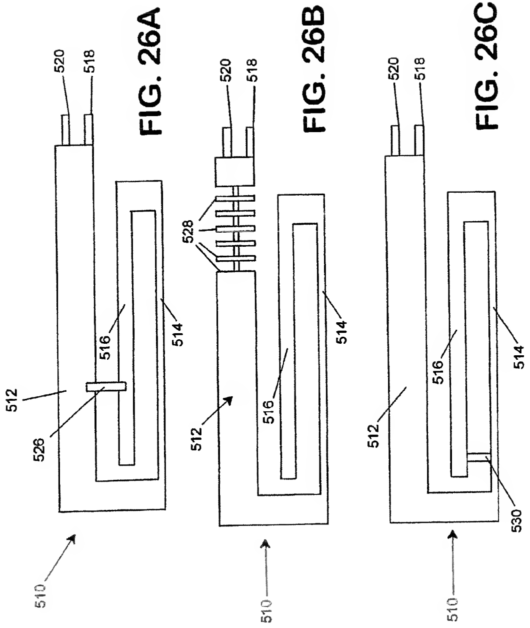


FIG. 26A

FIG. 26B

FIG. 26C

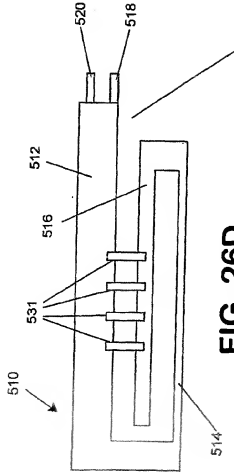


FIG. 26D

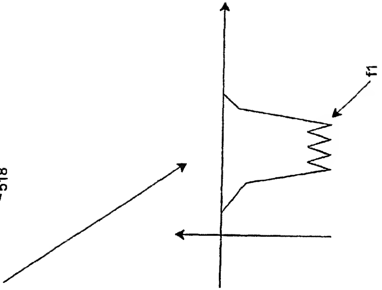


FIG. 26E

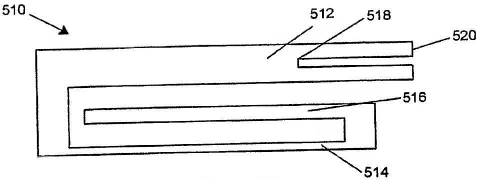


FIG. 26F

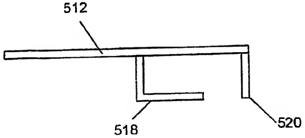


FIG. 26G

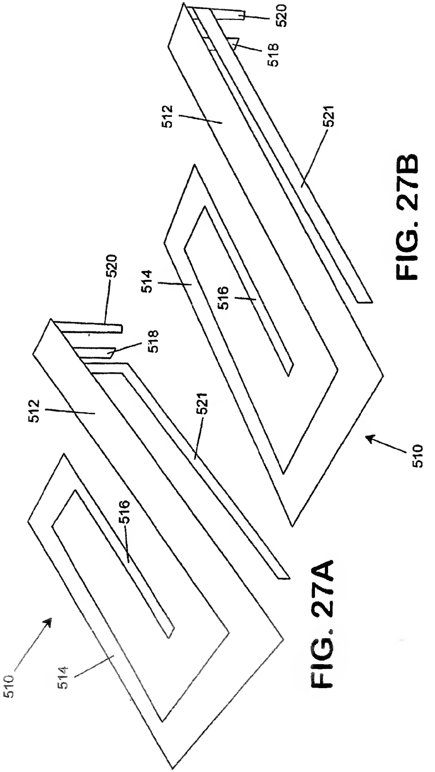


FIG. 27A

FIG. 27B

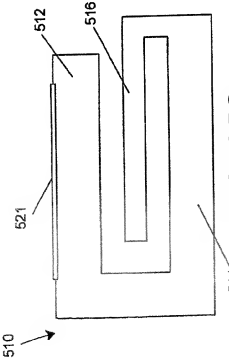


FIG. 27C

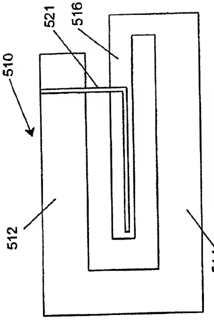


FIG. 27D

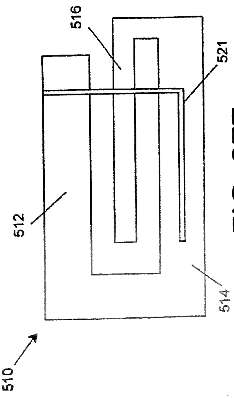


FIG. 27E

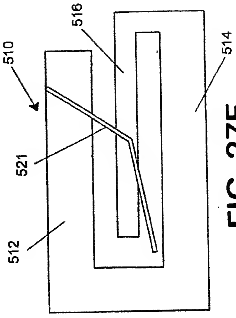


FIG. 27F

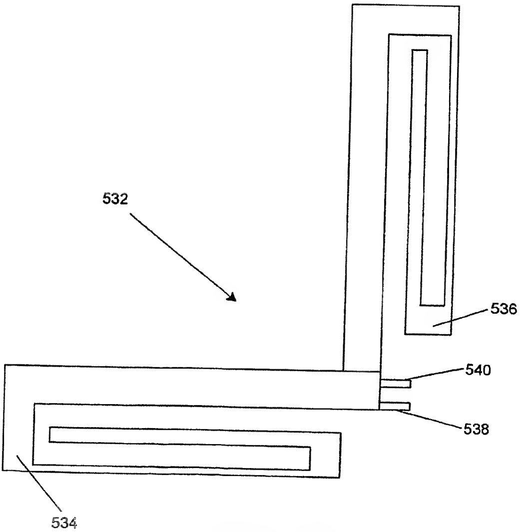


FIG. 28

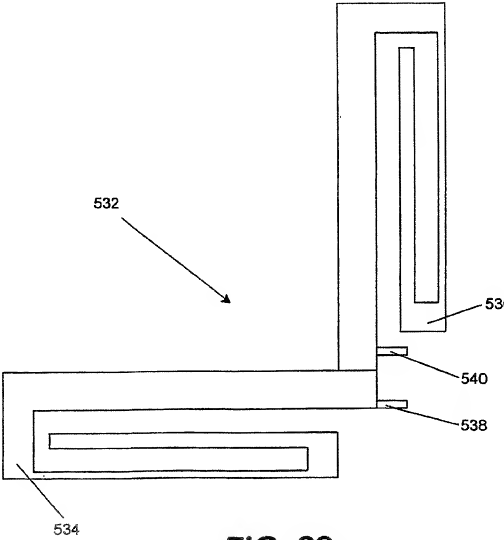


FIG. 29

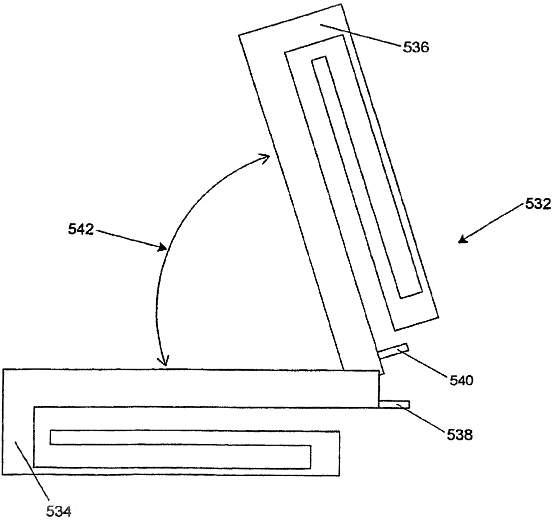


FIG. 30

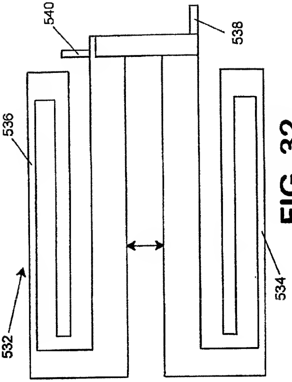


FIG. 32

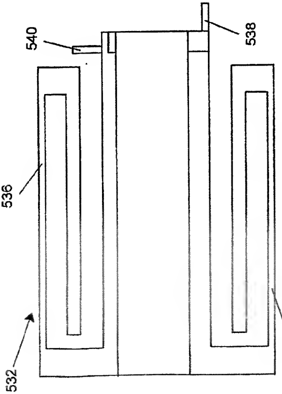


FIG. 31

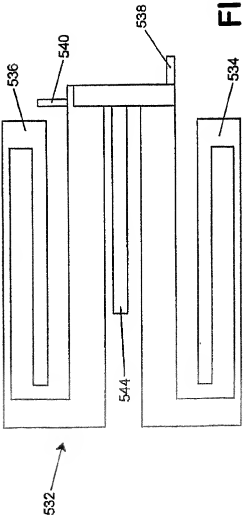


FIG. 33

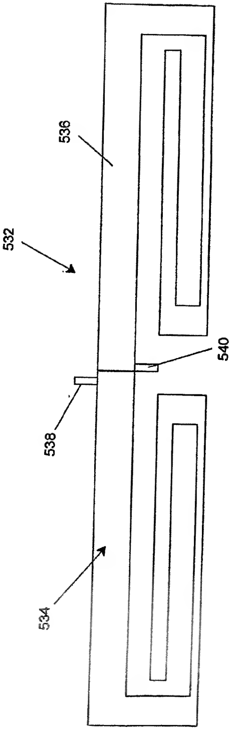


FIG. 34

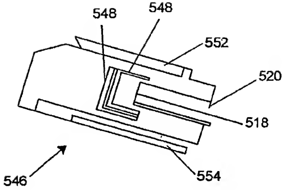


FIG. 35A

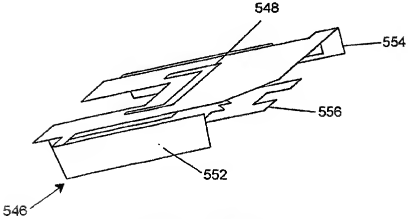


FIG. 35B

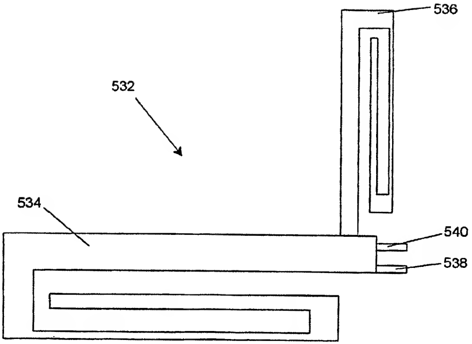


FIG. 36

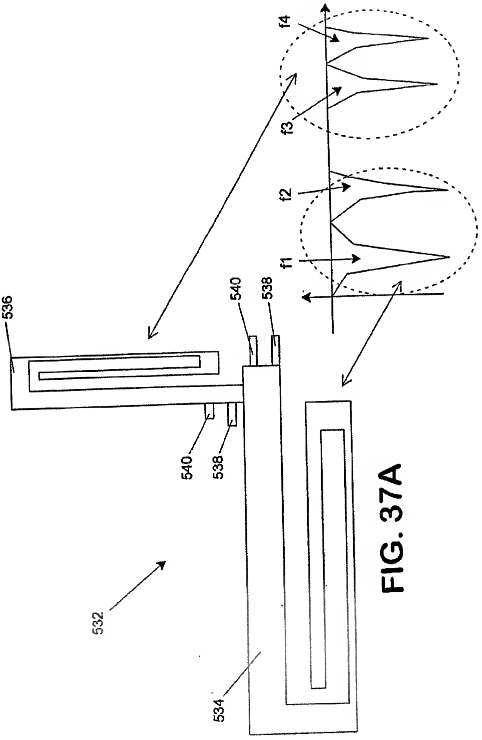


FIG. 37A

FIG. 37B

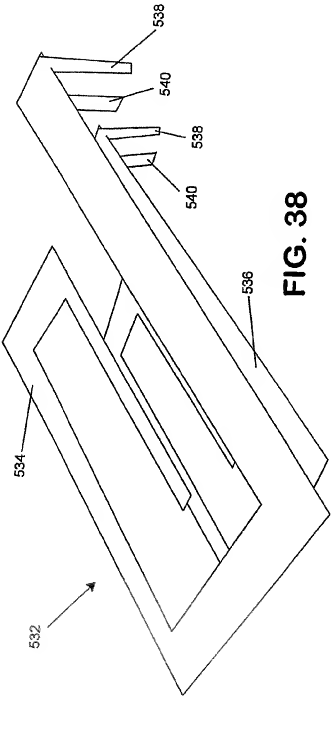


FIG. 38

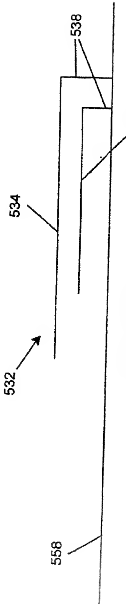


FIG. 39

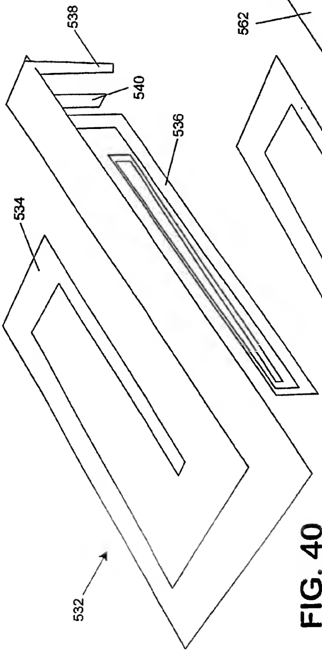


FIG. 40

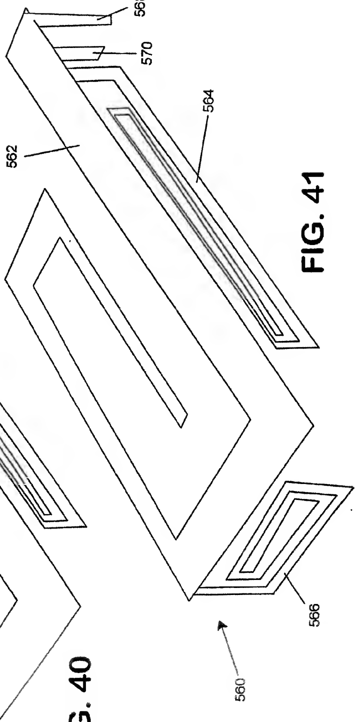


FIG. 41

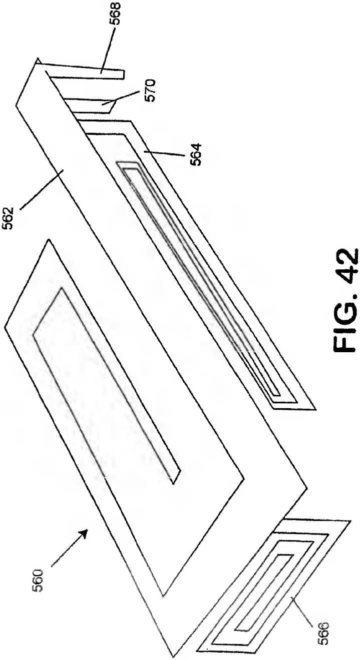


FIG. 42

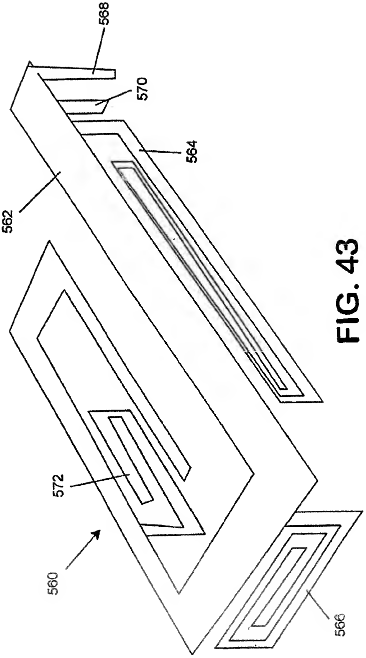


FIG. 43

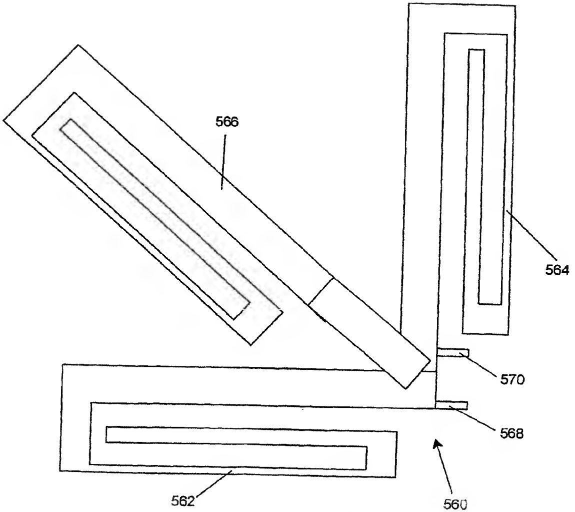


FIG. 44

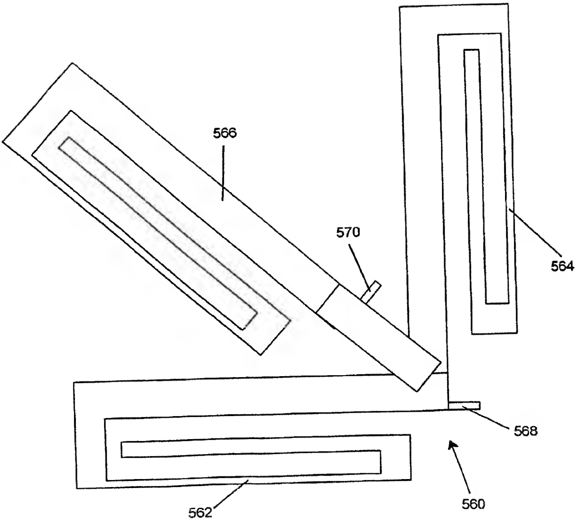


FIG. 45

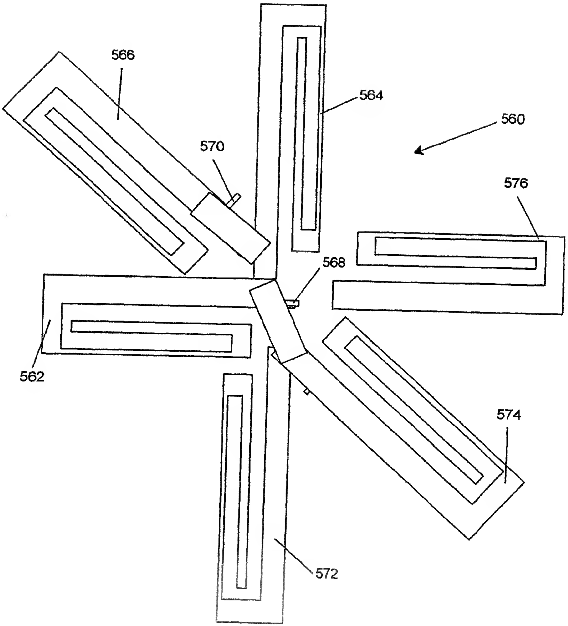


FIG. 46

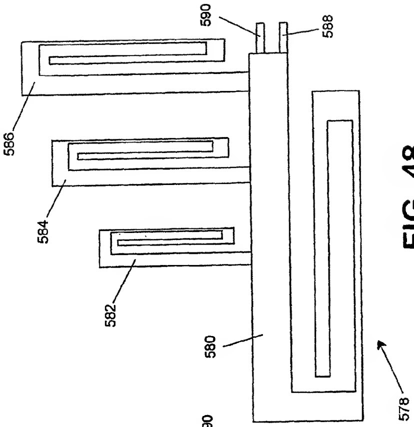


FIG. 48

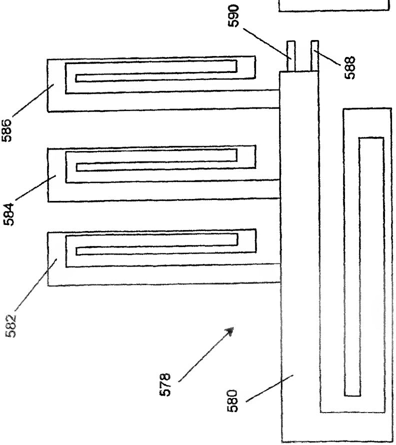


FIG. 47

INTERNATIONAL SEARCH REPORT	International application No. PCT/US03/12725

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :H01Q 1/38, 1/24
US CL :343/700ms, 702
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 343/700ms, 702, 745, 749, 846, 848, 830, 831

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,680,144 A (SANAD) 21 October 1997 (21/10/1997), see figures 11-13.	1-23,27-45, and 49-50N
Y, P	US 6,538,621 B1 (SIEVENPIPER et al) 25 March 2003 (25/03/2003), see figure 6.	24-26 and 46-48
A, P	US 6,456,243 B1 (POILASNE et al) 24 September 2002 (24/09/2002), see figure 5.	1-50
X, P	US 2002/0126052 A1 (BOYLE) 12 September 2002 (12/09/2002), see figure 14.	51,60,63,72,75, and 84

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 JUNE 2003	29 SEP 2003
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer HOANGANH LE Diane Smith Telephone No. (703) 308-4921